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Savaglio et al.

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(54) **SYSTEM FOR CONVERTING BETWEEN HIGHER-LAYER PACKETS AND LOWER-LAYER PACKETS, A METHOD AND A BASE STATION SERVER THEREOF**

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(51) **Int. Cl.**
H04W 88/08 (2009.01)

(52) **U.S. Cl.**
CPC ***H04W 88/08*** (2013.01)

(58) **Field of Classification Search**
CPC H04W 88/08; H04W 36/0011; H04L 2212/00; H04L 61/2592
See application file for complete search history.

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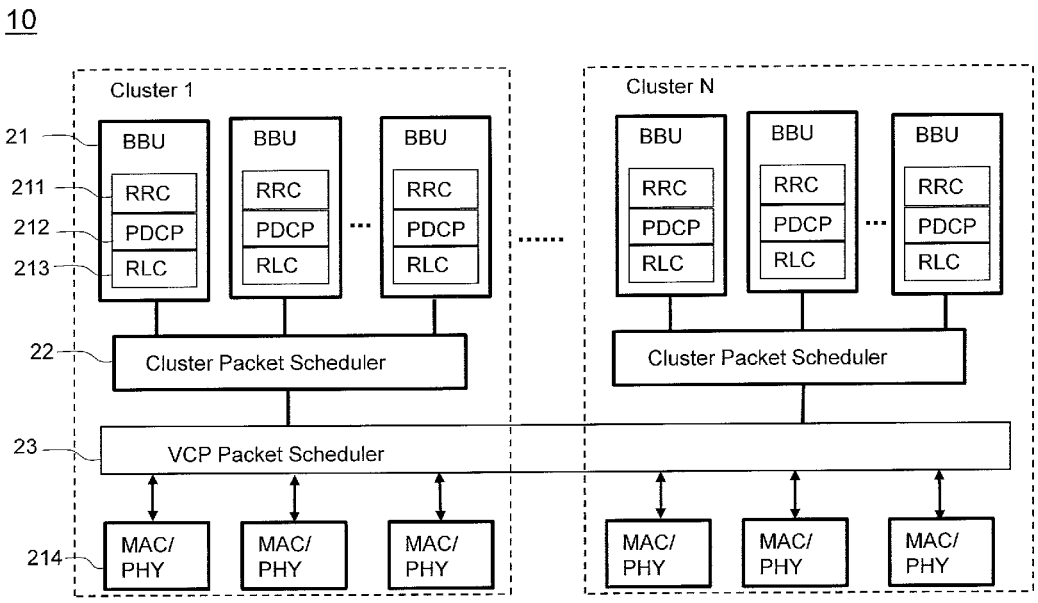
(57) **ABSTRACT**

The invention provides a system, method and base station server. According to an embodiment, a system for converting between higher-layer packets and lower-layer packets comprises a downlink base station server and an uplink base station client. The downlink base station server performs conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet by: receiving the at least one downlink higher-layer packet; converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet; and transmitting the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device. The uplink base station client performs conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet and transmits the at least one uplink higher-layer packet to an uplink base station server.

22 Claims, 15 Drawing Sheets



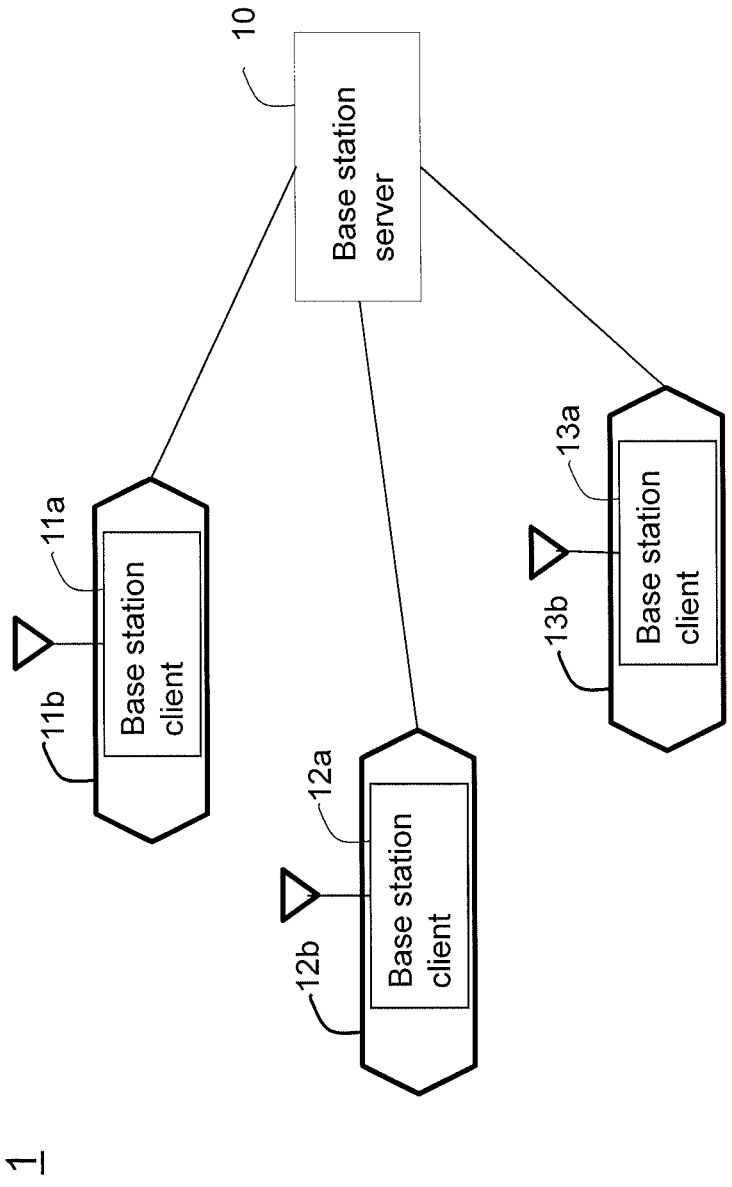

1
10
Base station server
11a
Base station client
11b
12a
Base station client
12b
13a
Base station client
13b

Figure 1

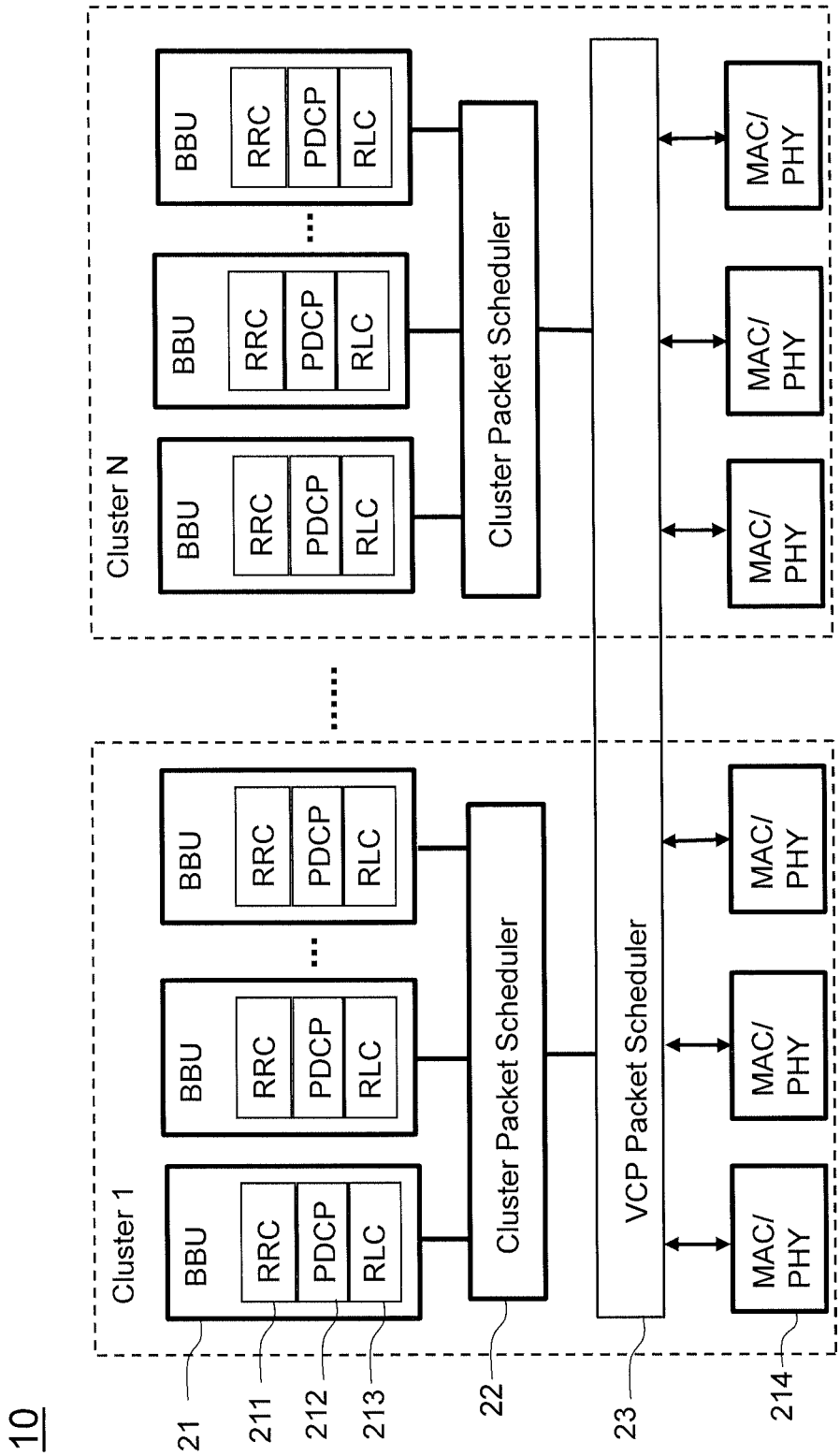

10
Cluster 1
Cluster N
BBU
RRC
PDCP
RLC
MAC/
PHY
Cluster Packet Scheduler
VCP Packet Scheduler
21
211
212
213
22
23
214

Figure 2

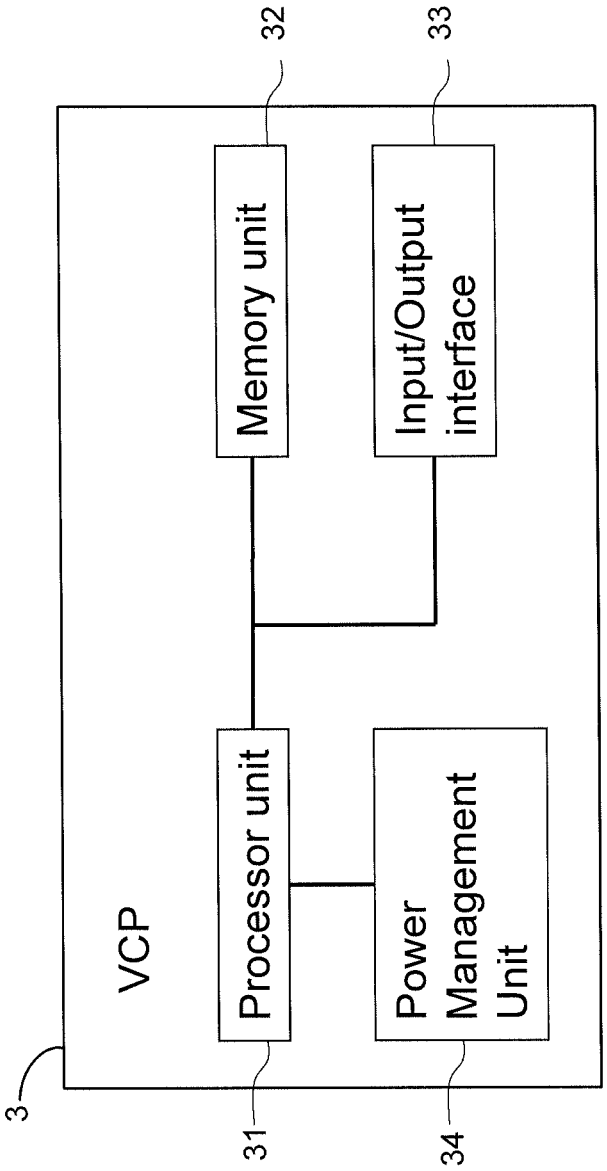

32
33
Memory unit
Input/Output interface
VCP
Processor unit
Power Management Unit
3
31
34

Figure 3

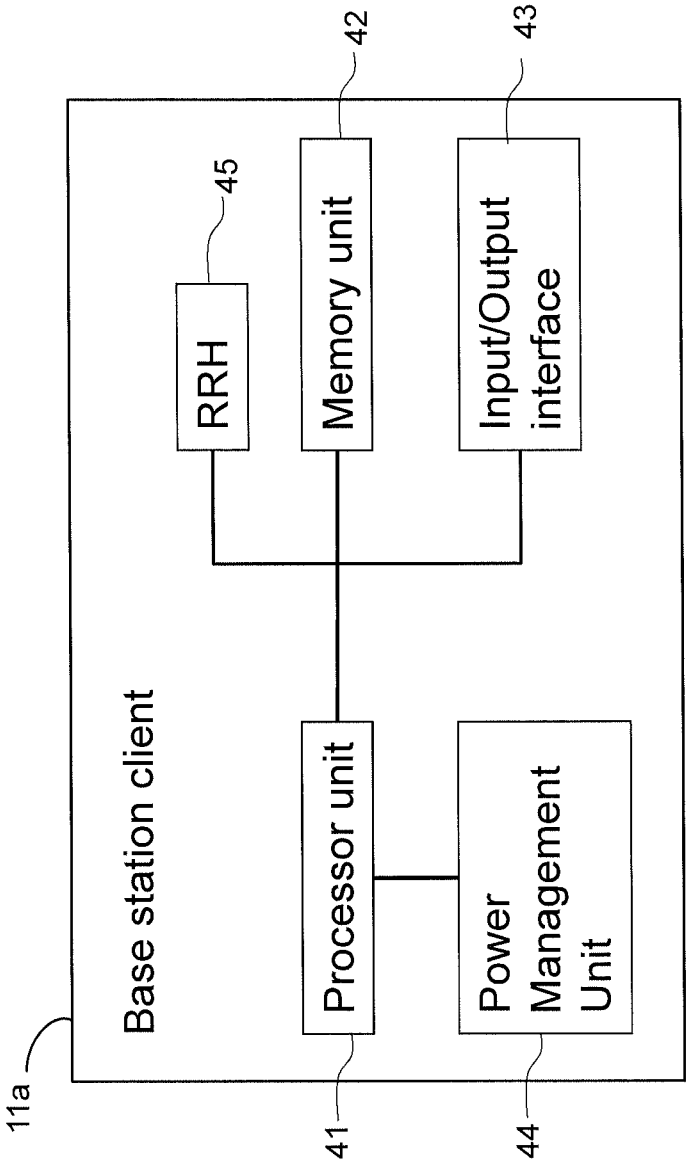

11a
Base station client
Processor unit
Power Management Unit
RRH
Memory unit
Input/Output interface
41
44
45
42
43

Figure 4

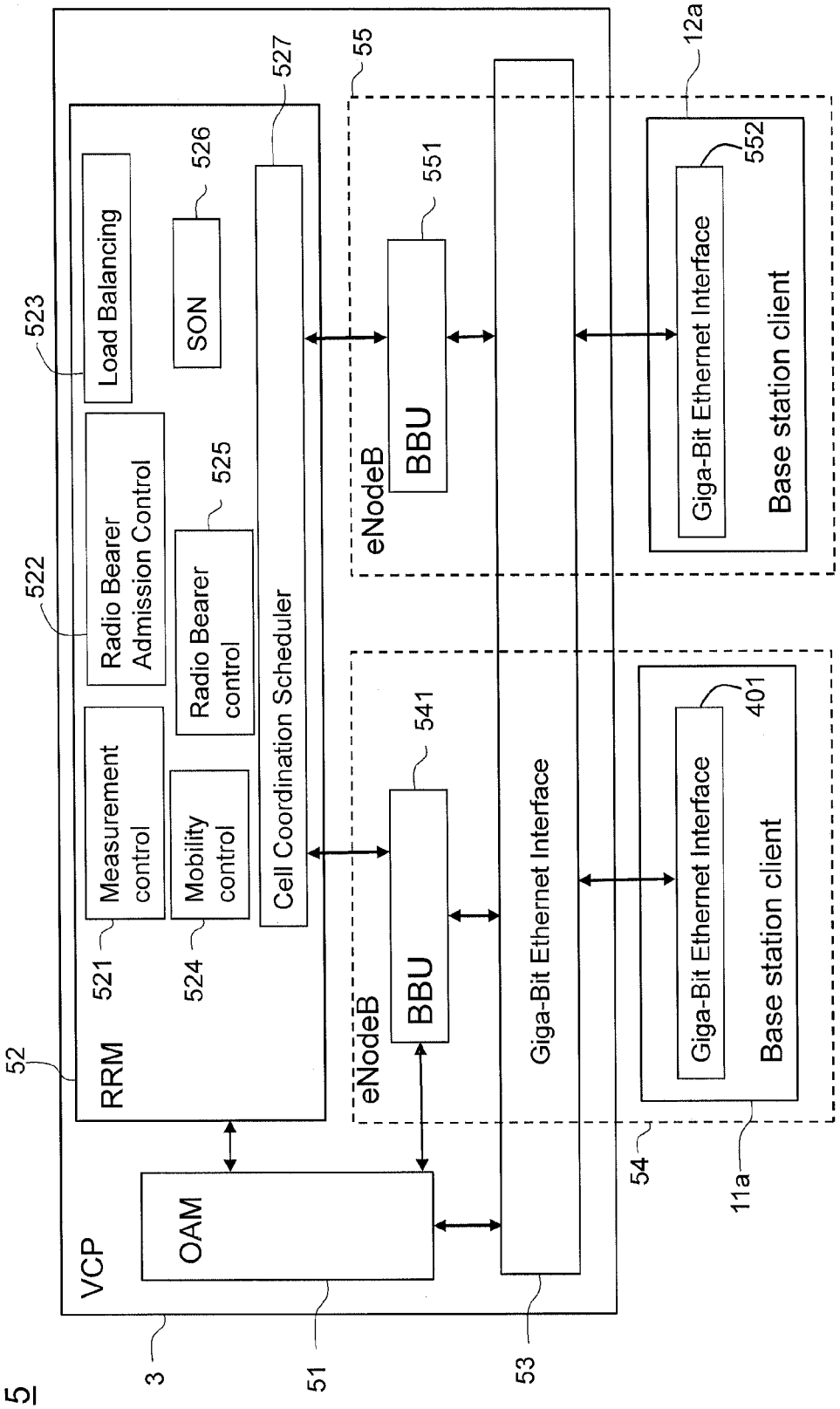

5
VCP
3
OAM
51
RRM
52
Measurement control
521
Mobility control
524
Radio Bearer Admission Control
522
Radio Bearer control
525
Load Balancing
523
SON
526
Cell Coordination Scheduler
527
Giga-Bit Ethernet Interface
53
eNodeB
55
BBU
551
541
Giga-Bit Ethernet Interface
552
401
Base station client
12a
11a
54

Figure 5

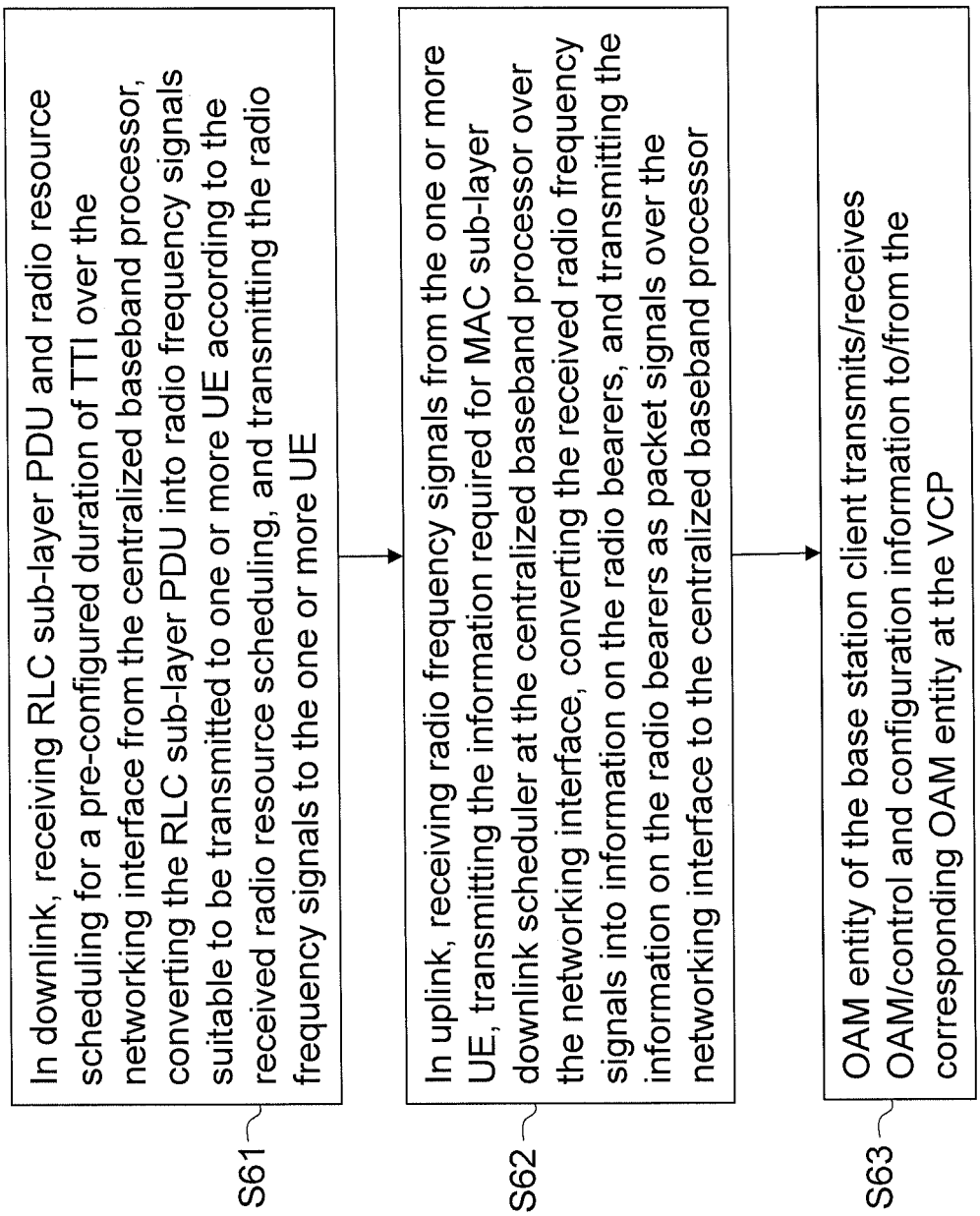

In downlink, receiving RLC sub-layer PDU and radio resource scheduling for a pre-configured duration of TTI over the networking interface from the centralized baseband processor, converting the RLC sub-layer PDU into radio frequency signals suitable to be transmitted to one or more UE according to the received radio resource scheduling, and transmitting the radio frequency signals to the one or more UE
S61
In uplink, receiving radio frequency signals from the one or more UE, transmitting the information required for MAC sub-layer downlink scheduler at the centralized baseband processor over the networking interface, converting the received radio frequency signals into information on the radio bearers, and transmitting the information on the radio bearers as packet signals over the networking interface to the centralized baseband processor
S62
OAM entity of the base station client transmits/receives OAM/control and configuration information to/from the corresponding OAM entity at the VCP
S63

Figure 6

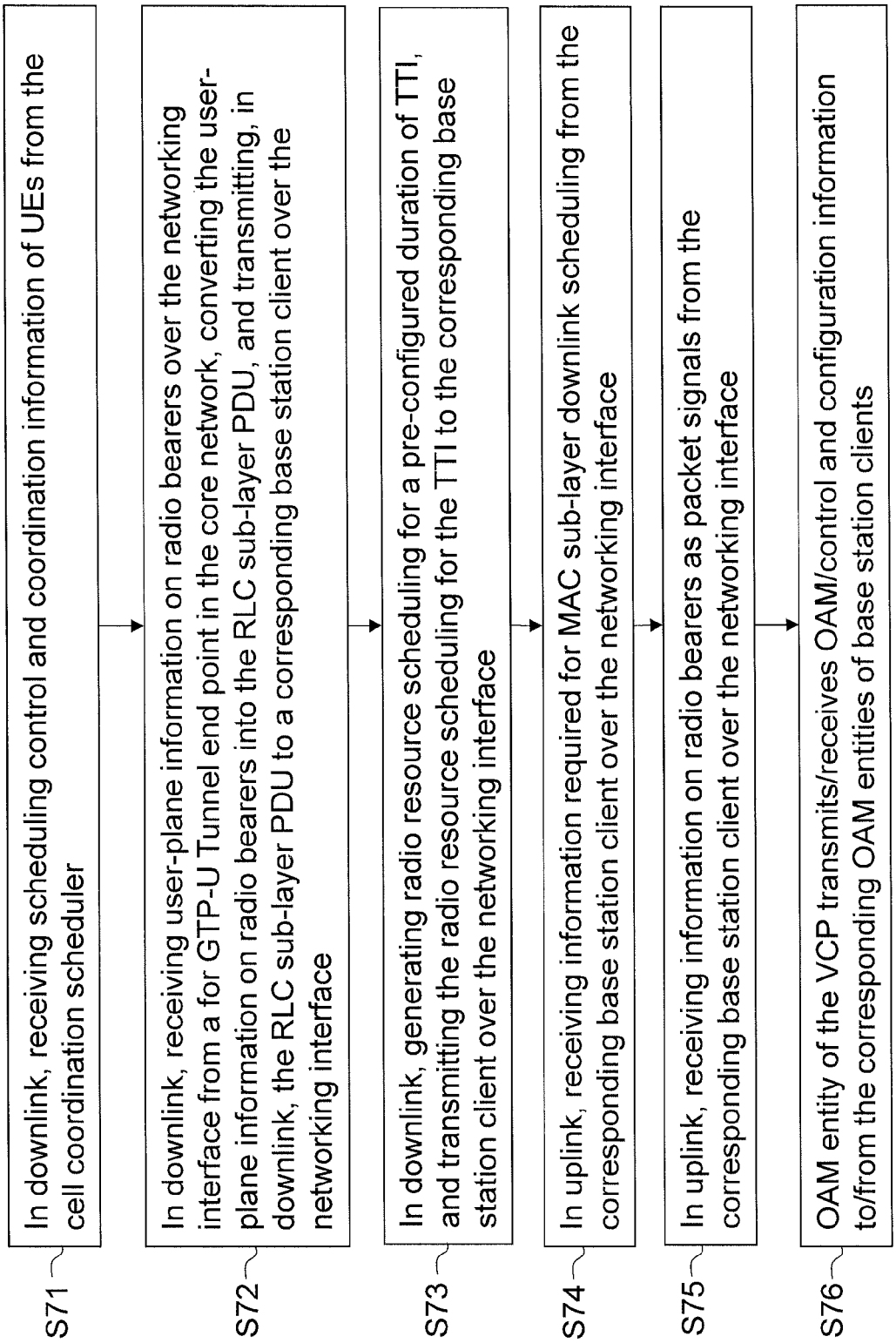

S71
In downlink, receiving scheduling control and coordination information of UEs from the cell coordination scheduler
S72
In downlink, receiving user-plane information on radio bearers over the networking interface from a for GTP-U Tunnel end point in the core network, converting the user-plane information on radio bearers into the RLC sub-layer PDU, and transmitting, in downlink, the RLC sub-layer PDU to a corresponding base station client over the networking interface
S73
In downlink, generating radio resource scheduling for a pre-configured duration of TTI, and transmitting the radio resource scheduling for the TTI to the corresponding base station client over the networking interface
S74
In uplink, receiving information required for MAC sub-layer downlink scheduling from the corresponding base station client over the networking interface
S75
In uplink, receiving information on radio bearers as packet signals from the corresponding base station client over the networking interface
S76
OAM entity of the VCP transmits/receives OAM/control and configuration information to/from the corresponding OAM entities of base station clients

Figure 7

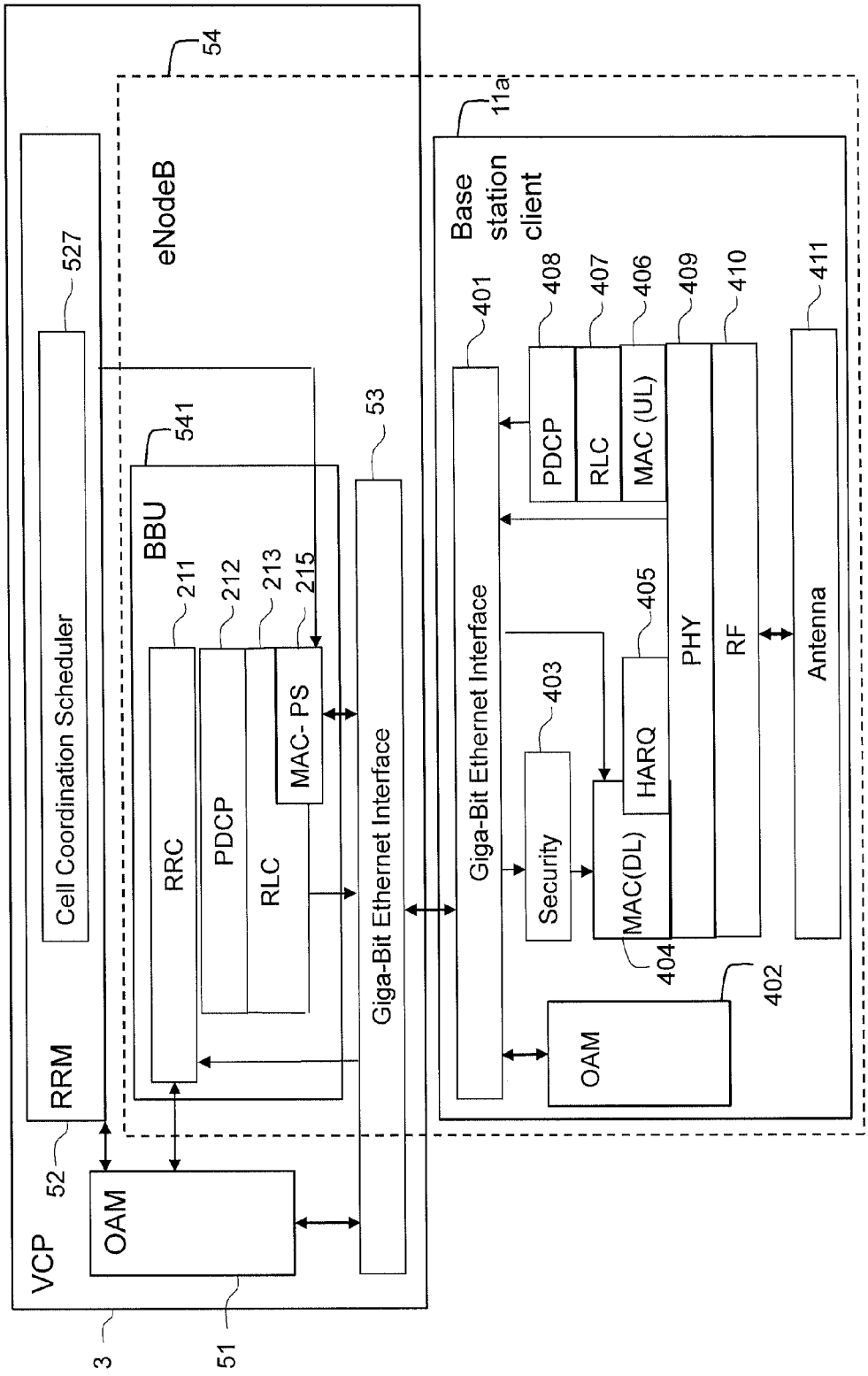

5
VCP
3
OAM
51
52
RRM
Cell Coordination Scheduler
527
eNodeB
54
BBU
541
RRC
211
PDCP
212
RLC
213
MAC- PS
215
Giga-Bit Ethernet Interface
53
Base station client
11a
Giga-Bit Ethernet Interface
401
Security
403
MAC(DL)
HARQ
405
404
OAM
402
PDCP
408
RLC
407
MAC (UL)
406
PHY
409
RF
410
Antenna
411

Figure 8

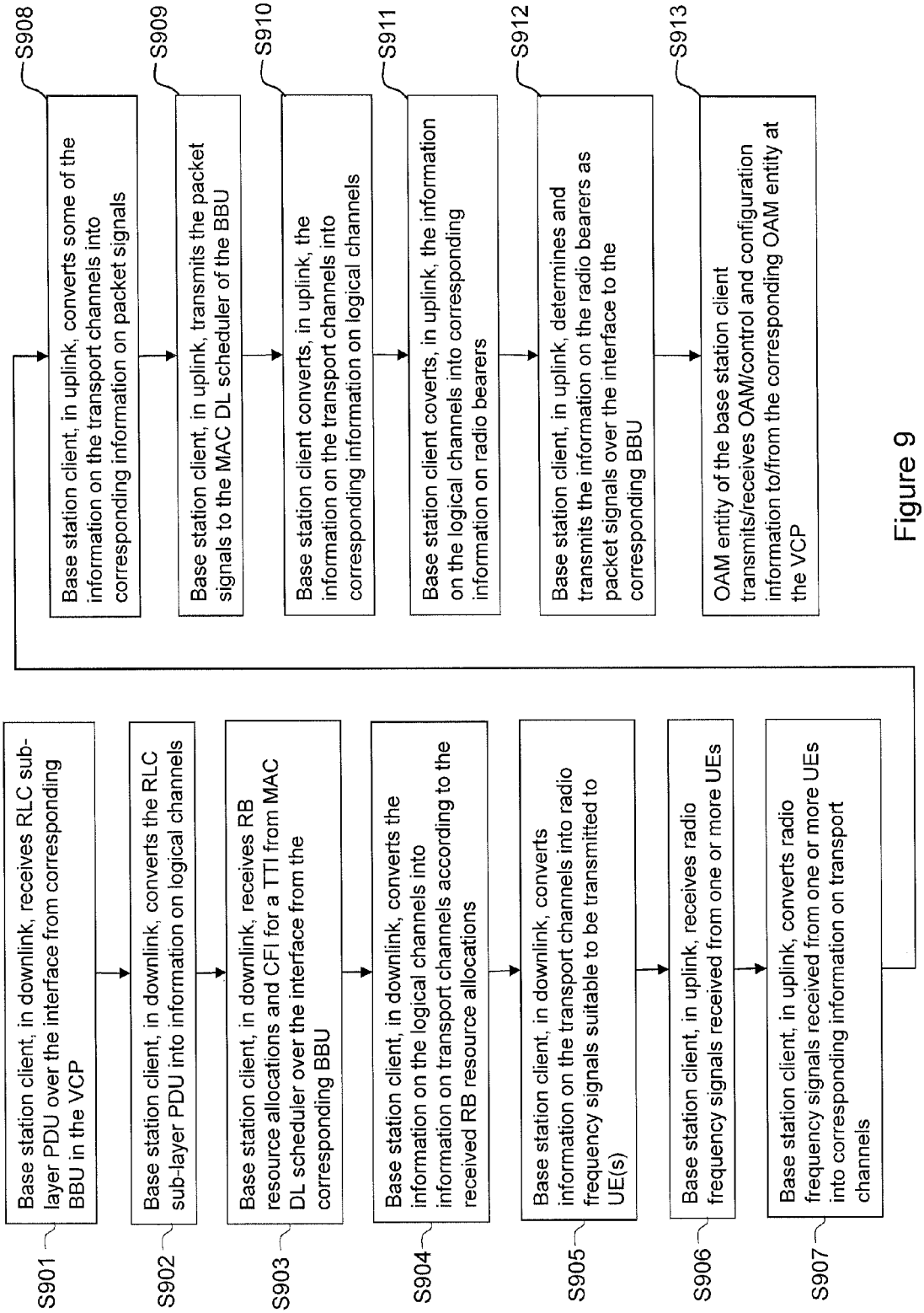

S901
Base station client, in downlink, receives RLC sub-layer PDU over the interface from corresponding BBU in the VCP
S902
Base station client, in downlink, converts the RLC sub-layer PDU into information on logical channels
S903
Base station client, in downlink, receives RB resource allocations and CFI for a TTI from MAC DL scheduler over the interface from the corresponding BBU
S904
Base station client, in downlink, converts the information on the logical channels into information on transport channels according to the received RB resource allocations
S905
Base station client, in downlink, converts information on the transport channels into radio frequency signals suitable to be transmitted to UE(s)
S906
Base station client, in uplink, receives radio frequency signals received from one or more UEs
S907
Base station client, in uplink, converts radio frequency signals received from one or more UEs into corresponding information on transport channels
S908
Base station client, in uplink, converts some of the information on the transport channels into corresponding information on packet signals
S909
Base station client, in uplink, transmits the packet signals to the MAC DL scheduler of the BBU
S910
Base station client converts, in uplink, the information on the transport channels into corresponding information on logical channels
S911
Base station client coverts, in uplink, the information on the logical channels into corresponding information on radio bearers
S912
Base station client, in uplink, determines and transmits the information on the radio bearers as packet signals over the interface to the corresponding BBU
S913
OAM entity of the base station client transmits/receives OAM/control and configuration information to/from the corresponding OAM entity at the VCP

Figure 9

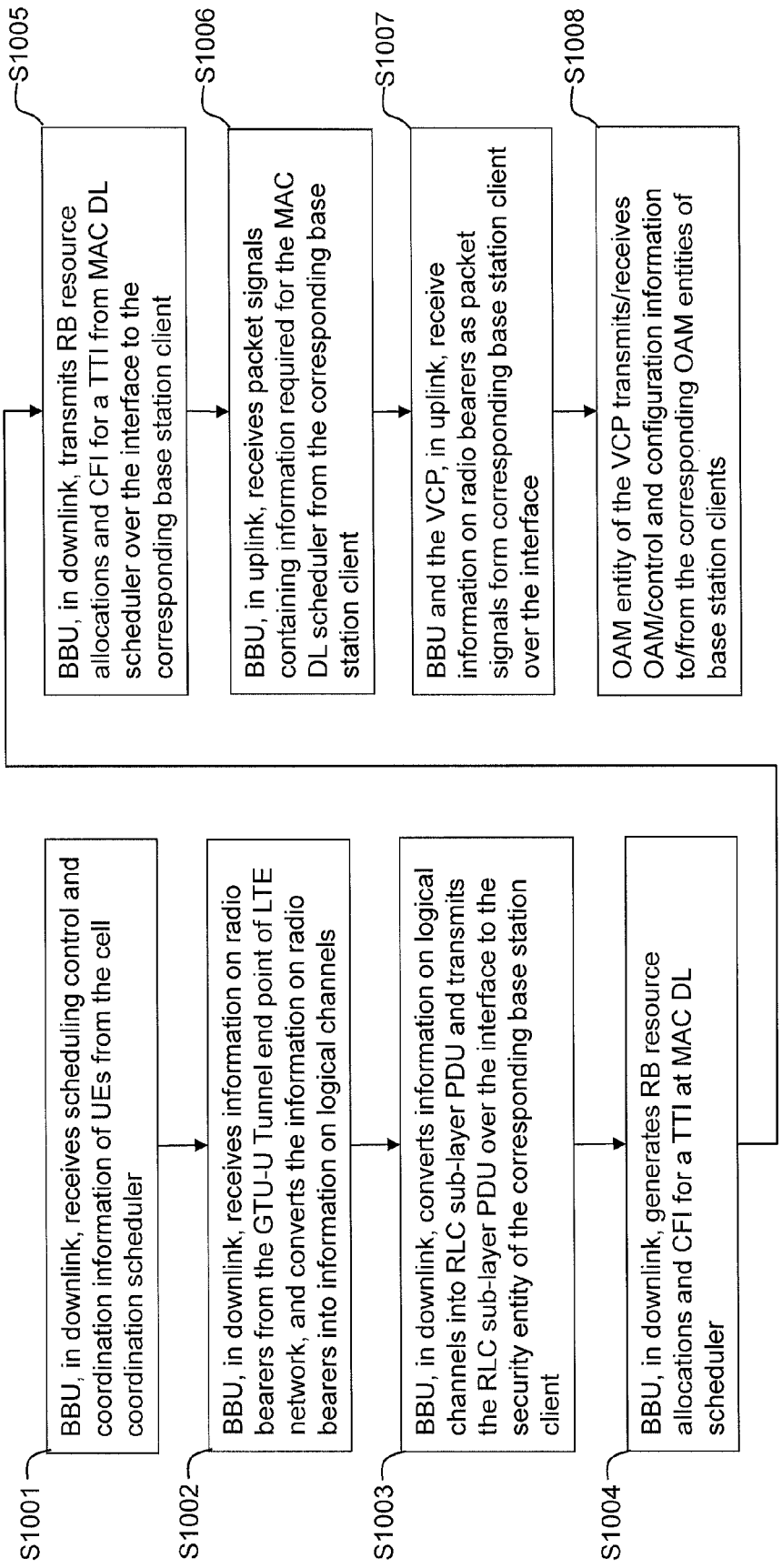

S1001
BBU, in downlink, receives scheduling control and coordination information of UEs from the cell coordination scheduler
S1002
BBU, in downlink, receives information on radio bearers from the GTU-U Tunnel end point of LTE network, and converts the information on radio bearers into information on logical channels
S1003
BBU, in downlink, converts information on logical channels into RLC sub-layer PDU and transmits the RLC sub-layer PDU over the interface to the security entity of the corresponding base station client
S1004
BBU, in downlink, generates RB resource allocations and CFI for a TTI at MAC DL scheduler
S1005
BBU, in downlink, transmits RB resource allocations and CFI for a TTI from MAC DL scheduler over the interface to the corresponding base station client
S1006
BBU, in uplink, receives packet signals containing information required for the MAC DL scheduler from the corresponding base station client
S1007
BBU and the VCP, in uplink, receive information on radio bearers as packet signals form corresponding base station client over the interface
S1008
OAM entity of the VCP transmits/receives OAM/control and configuration information to/from the corresponding OAM entities of base station clients

Figure 10

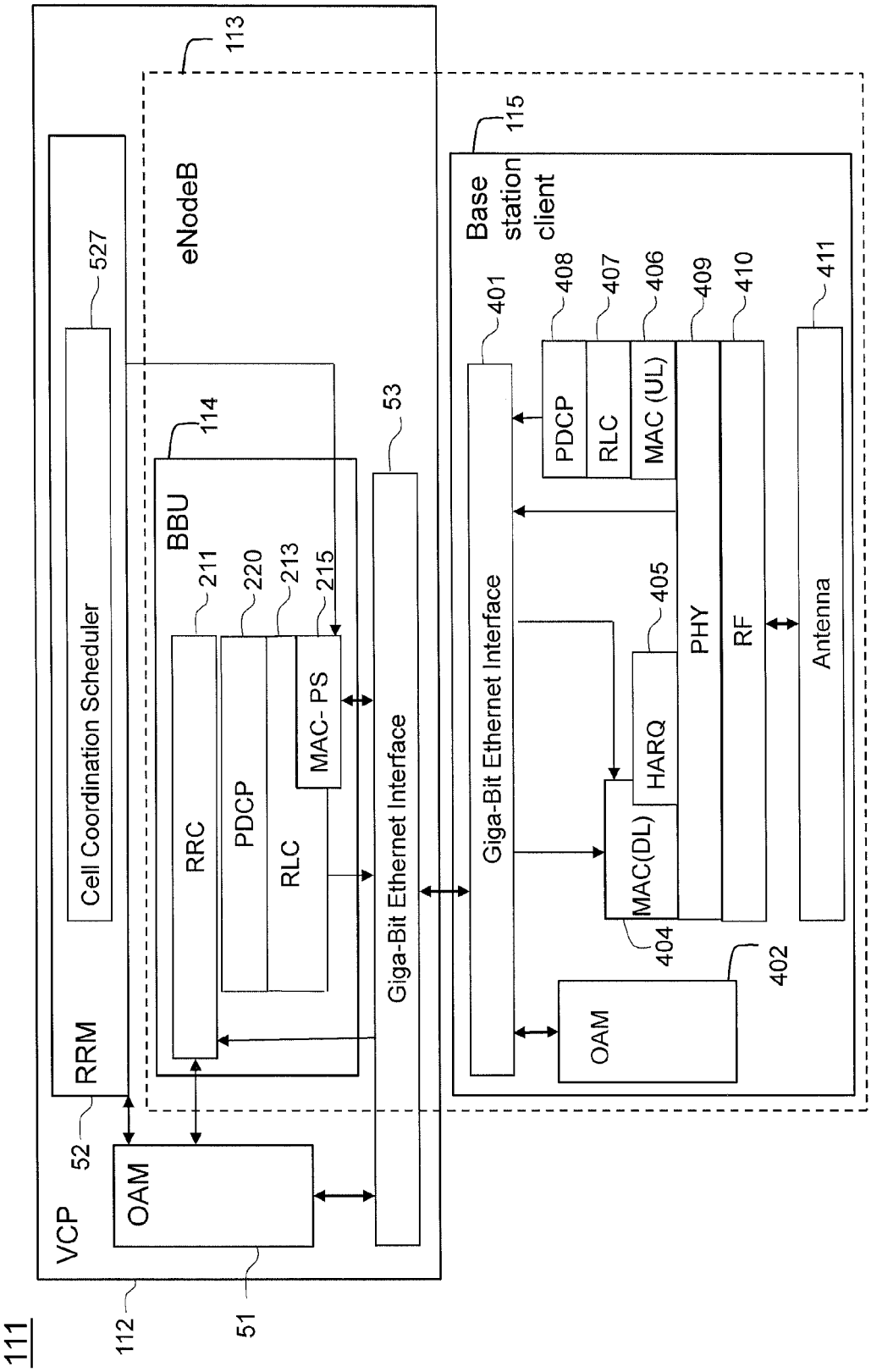

111
112
51
VCP
OAM
52
RRM
Cell Coordination Scheduler
527
113
eNodeB
BBU
114
RRC
211
PDCP
220
RLC
213
MAC- PS
215
53
Giga-Bit Ethernet Interface
Base station client
115
401
Giga-Bit Ethernet Interface
OAM
402
MAC(DL)
HARQ
404
405
PHY
RF
Antenna
411
PDCP
408
RLC
407
MAC (UL)
406
409
410

Figure 11

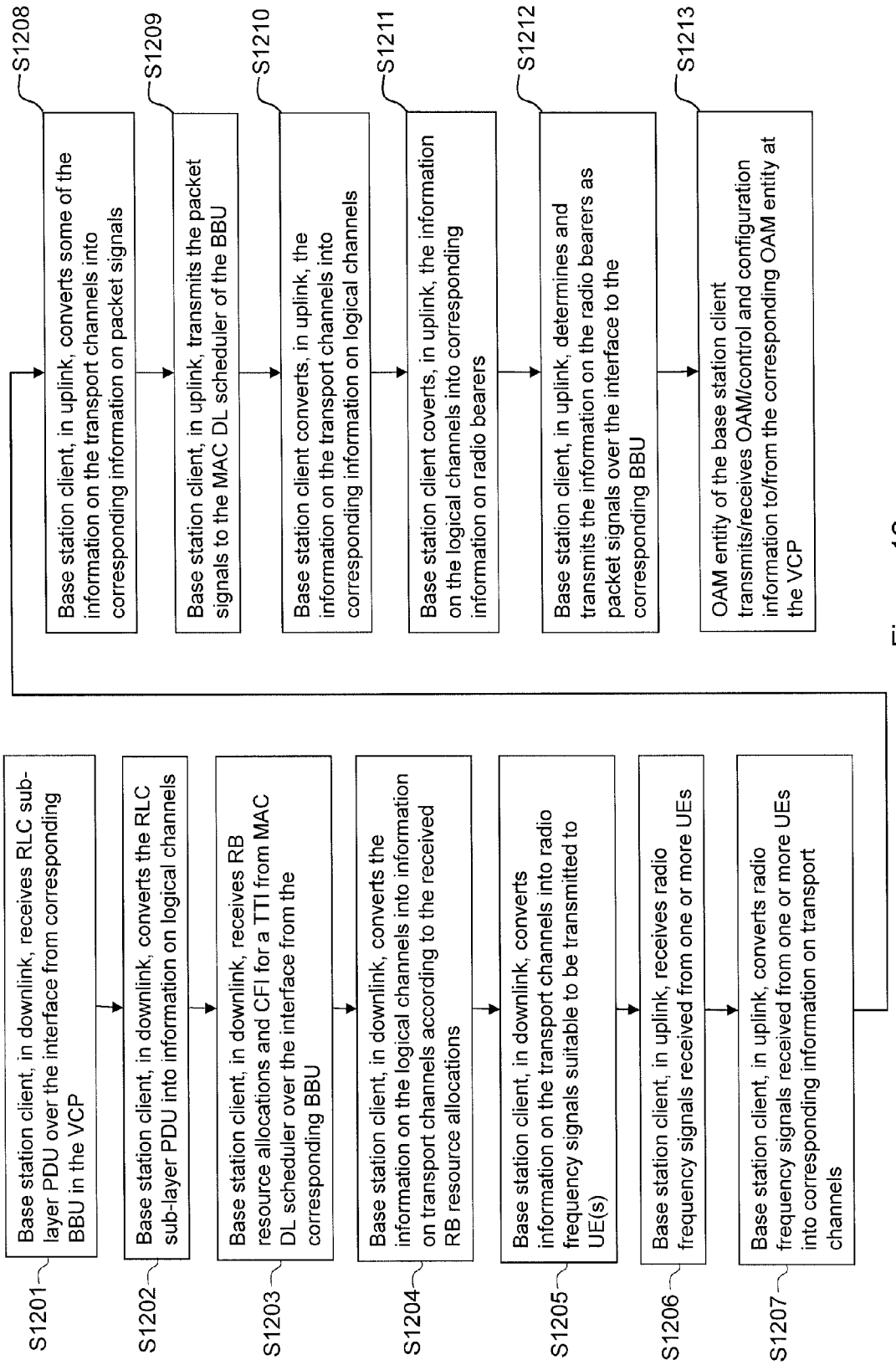

S1201
Base station client, in downlink, receives RLC sub-layer PDU over the interface from corresponding BBU in the VCP
S1202
Base station client, in downlink, converts the RLC sub-layer PDU into information on logical channels
S1203
Base station client, in downlink, receives RB resource allocations and CFI for a TTI from MAC DL scheduler over the interface from the corresponding BBU
S1204
Base station client, in downlink, converts the information on the logical channels into information on transport channels according to the received RB resource allocations
S1205
Base station client, in downlink, converts information on the transport channels into radio frequency signals suitable to be transmitted to UE(s)
S1206
Base station client, in uplink, receives radio frequency signals received from one or more UEs
S1207
Base station client, in uplink, converts radio frequency signals received from one or more UEs into corresponding information on transport channels
S1208
Base station client, in uplink, converts some of the information on the transport channels into corresponding information on packet signals
S1209
Base station client, in uplink, transmits the packet signals to the MAC DL scheduler of the BBU
S1210
Base station client converts, in uplink, the information on the transport channels into corresponding information on logical channels
S1211
Base station client coverts, in uplink, the information on the logical channels into corresponding information on radio bearers
S1212
Base station client, in uplink, determines and transmits the information on the radio bearers as packet signals over the interface to the corresponding BBU
S1213
OAM entity of the base station client transmits/receives OAM/control and configuration information to/from the corresponding OAM entity at the VCP

Figure 12

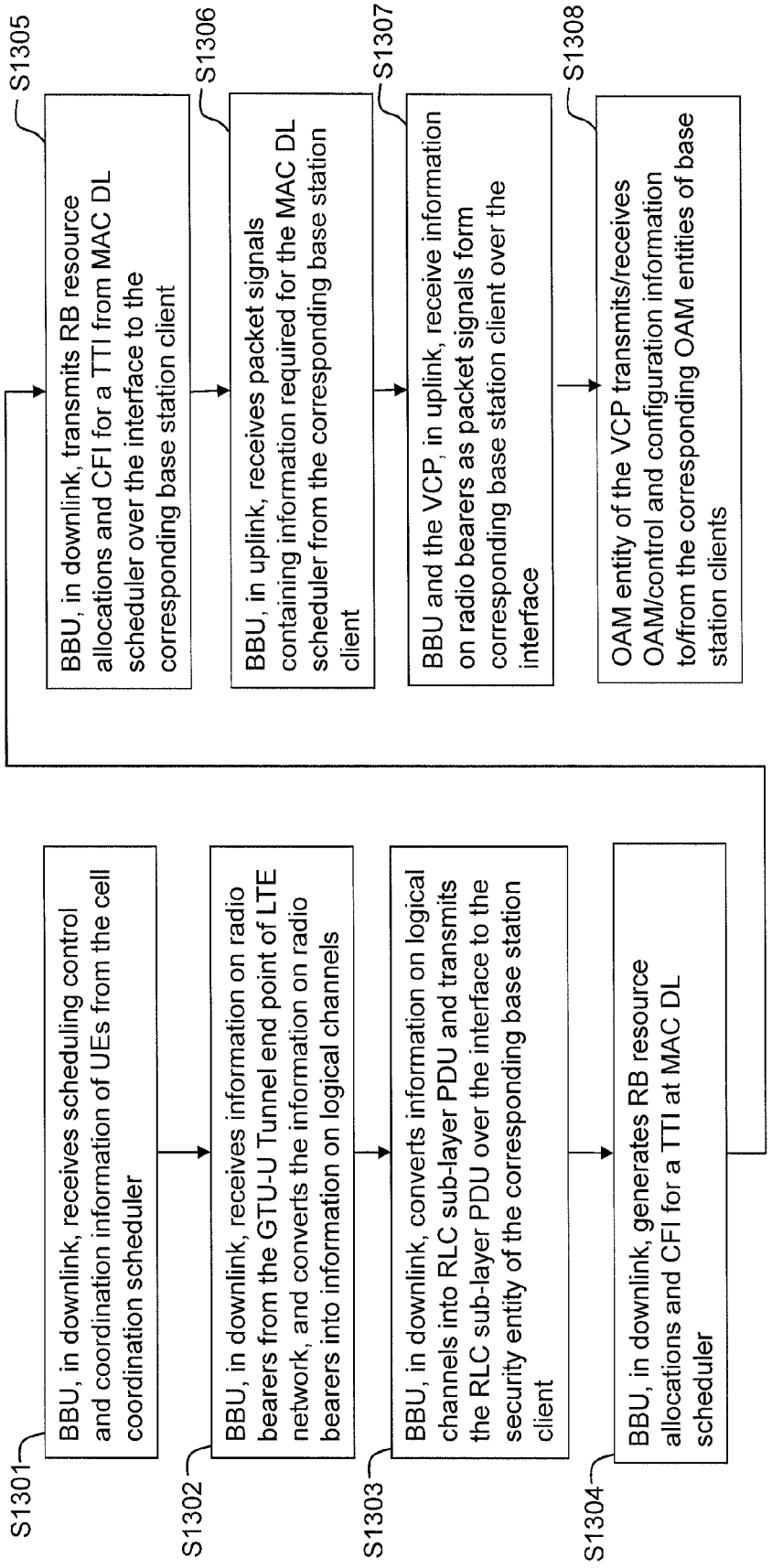

S1301
BBU, in downlink, receives scheduling control and coordination information of UEs from the cell coordination scheduler
S1302
BBU, in downlink, receives information on radio bearers from the GTU-U Tunnel end point of LTE network, and converts the information on radio bearers into information on logical channels
S1303
BBU, in downlink, converts information on logical channels into RLC sub-layer PDU and transmits the RLC sub-layer PDU over the interface to the security entity of the corresponding base station client
S1304
BBU, in downlink, generates RB resource allocations and CFI for a TTI at MAC DL scheduler
S1305
BBU, in downlink, transmits RB resource allocations and CFI for a TTI from MAC DL scheduler over the interface to the corresponding base station client
S1306
BBU, in uplink, receives packet signals containing information required for the MAC DL scheduler from the corresponding base station client
S1307
BBU and the VCP, in uplink, receive information on radio bearers as packet signals form corresponding base station client over the interface
S1308
OAM entity of the VCP transmits/receives OAM/control and configuration information to/from the corresponding OAM entities of base station clients

Figure 13

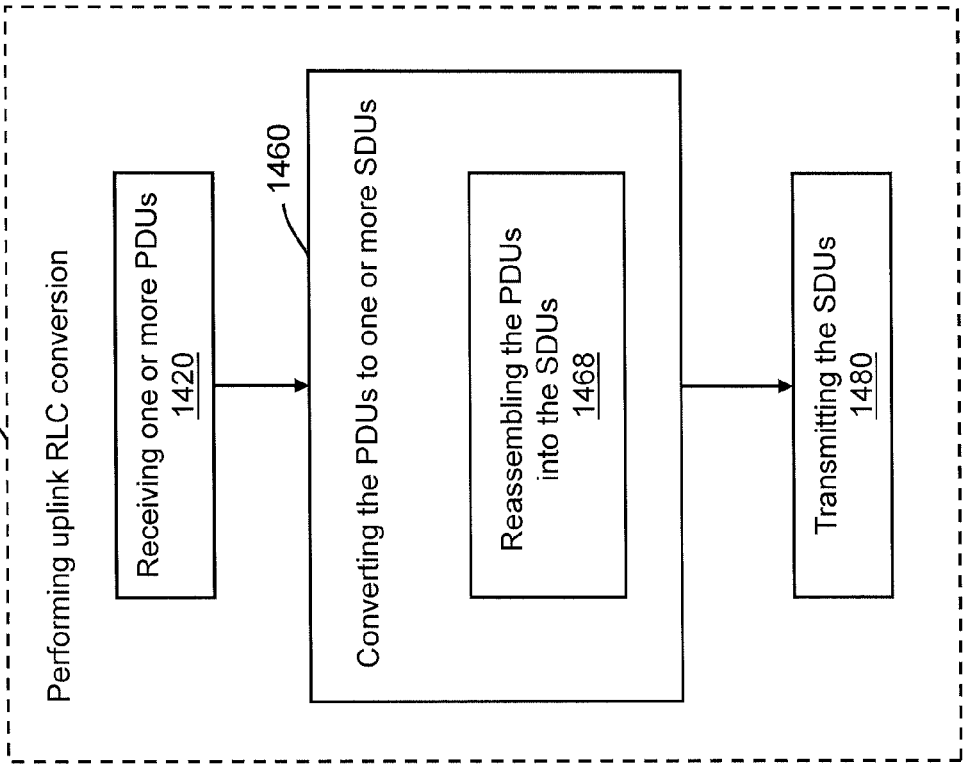


Figure 14B

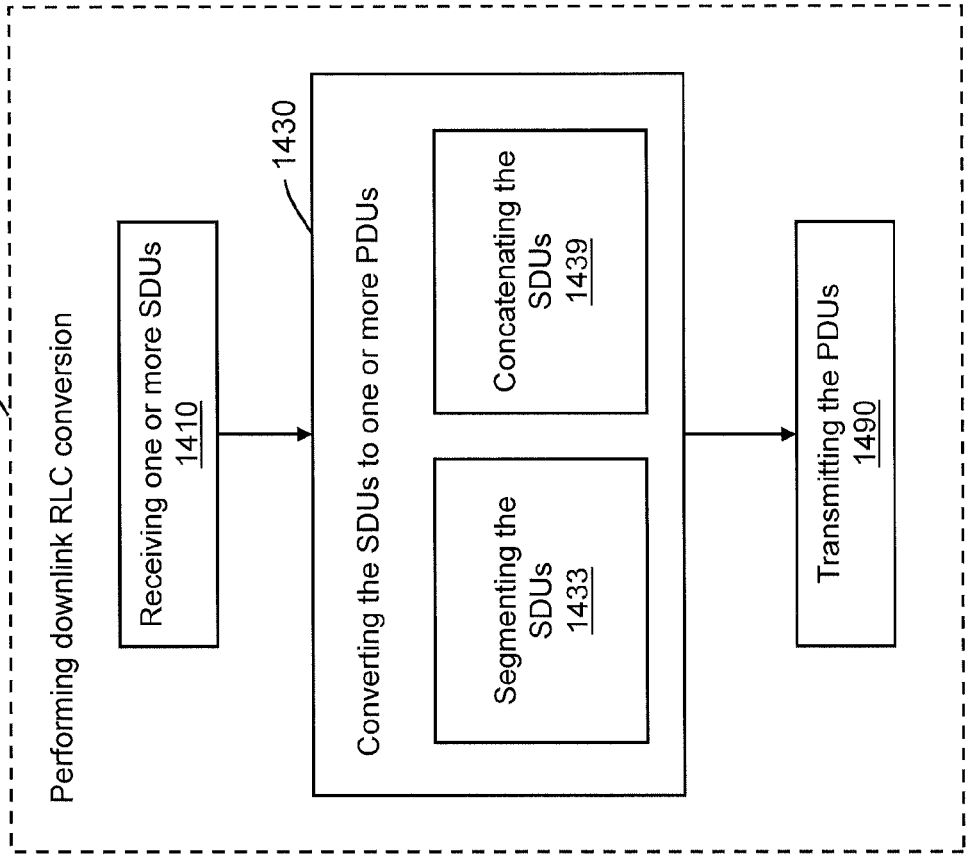


Figure 14A

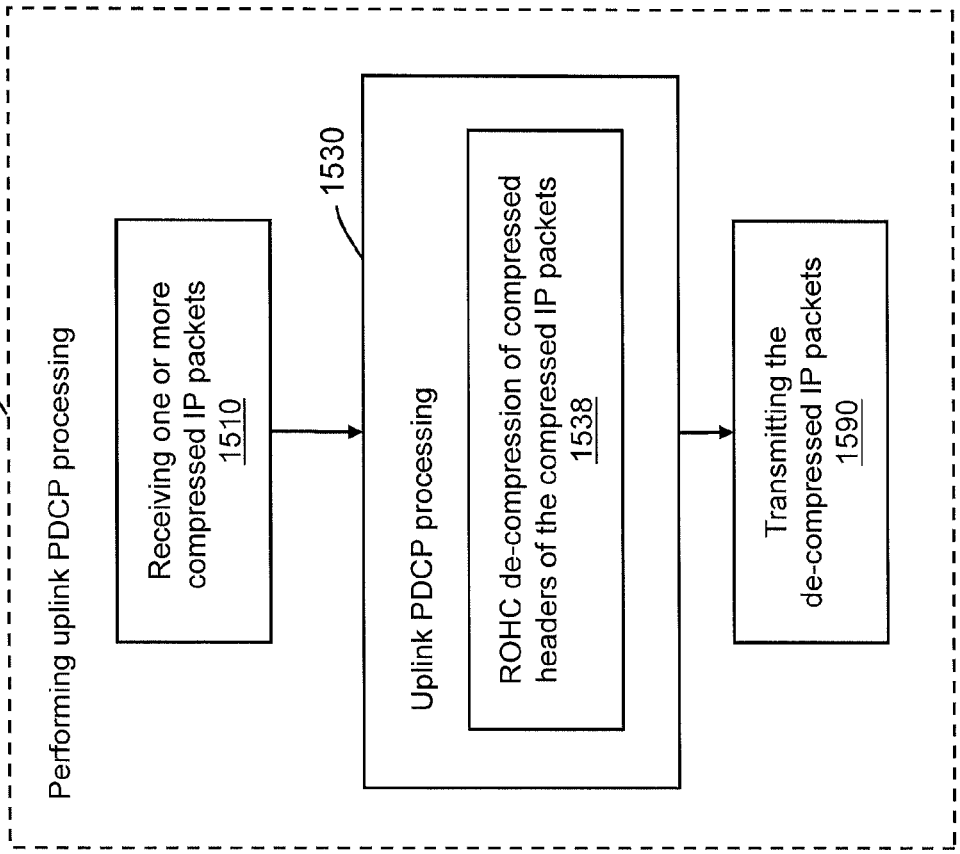


Figure 15B

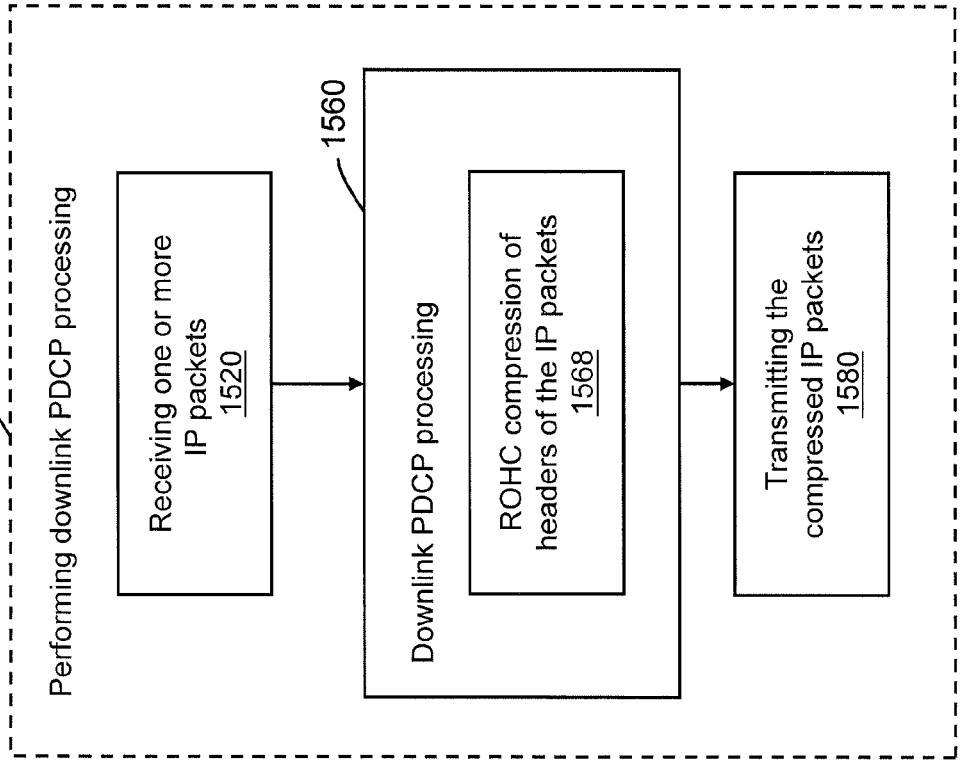


Figure 15A

SYSTEM FOR CONVERTING BETWEEN HIGHER-LAYER PACKETS AND LOWER-LAYER PACKETS, A METHOD AND A BASE STATION SERVER THEREOF

RELATED APPLICATION

The application claims the priority date of U.S. Provisional Patent Application No. 61/873,130 filed on 3 Sep. 2013, the disclosure of which is incorporated herein by reference.

FIELD OF INVENTION

The present invention is generally (but not exclusively) related to a system for converting between higher-layer packets and lower-layer packets, a method thereof and a base station server.

BACKGROUND

In contrast to a conventional Third Generation Project Partnership (3GPP) Universal Mobile Telecommunications System (UMTS) system where base stations (Node B) are connected to each other via Radio Network Controllers (RNC), the base stations (eNodeBs or eNBs) of a 3GPP Long Term Evolution (LTE) system may be connected to one another directly without a RNC. However, conventional eNodeBs conforming to the 3GPP LTE standard typically require significant upfront Capital Expenditure (CAPEX) (such as real estate costs for housing the Node B) and ongoing Operational Expenditure (OPEX) (such as energy costs for powering the Node B). Thus, there is a need for an improved or alternative system.

SUMMARY OF INVENTION

The present invention provides a system for converting between higher-layer packets and lower-layer packets, comprising:

a downlink base station server performs a conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet; and

an uplink base station client performs a conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet,

wherein the downlink base station server performs the conversion of the at least one downlink higher-layer packet to the at least one downlink lower-layer packet by:

receiving the at least one downlink higher-layer packet;

converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet; and

transmitting the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device, and

wherein the uplink base station client performs the conversion of the at least one uplink lower-layer packet to the at least one uplink higher-layer packet by:

receiving the at least one uplink lower-layer packet over an uplink channel from an uplink user device;

converting the at least one uplink lower-layer packet to the at least one uplink higher-layer packet; and

transmitting the at least one uplink higher-layer packet to an uplink base station server.

In an embodiment, the downlink base station server is located at a first site, and the uplink base station client is located at a second site remote from the first site.

In an embodiment, the system further comprises the uplink base station server, wherein the downlink base station server and the uplink base station server are implemented in the same device.

In an embodiment, the system further comprises the downlink base station client, wherein the downlink base station client and the uplink base station client are implemented in the same device.

In an embodiment, the downlink channel is a downlink radio channel, and the uplink channel is an uplink radio channel.

In an embodiment, the downlink base station server is connected to a plurality of downlink base station clients.

In an embodiment, the downlink base station server is connected to each downlink base station client via a respective one of a plurality of downlink optical fibre links.

In an embodiment, the downlink base station server is connected to each downlink base station client via a respective one of a plurality of downlink Ethernet connections.

In an embodiment, the uplink base station client is connected to the uplink base station server via an uplink optical fibre link.

In an embodiment, the uplink base station client is connected to the uplink base station server via an uplink Ethernet connection.

In an embodiment, each downlink higher-layer packet is a Service Data Unit (SDU) that conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard, each uplink higher-layer packet is a SDU that conforms to the 3GPP LTE standard, each downlink lower-layer packet is a Packet Data Unit (PDU) that conforms to the 3GPP LTE standard, and each uplink lower-layer packet is a PDU that conforms to the 3GPP LTE standard.

In an embodiment, each downlink higher-layer packet corresponds to an Internet Protocol (IP) packet, and each uplink higher-layer packet corresponds to an IP packet.

The present invention also provides a method of converting between higher-layer packets and lower-layer packets, comprising:

performing a conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet at a downlink base station server; and

performing a conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet at an uplink base station client,

wherein performing the conversion of the at least one downlink higher-layer packet to the at least one downlink lower-layer packet at the downlink base station server comprises:

receiving the at least one downlink higher-layer packet;

converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet; and

transmitting the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device, and

wherein performing the conversion of the at least one uplink lower-layer packet to the at least one uplink higher-layer packet at the uplink base station client comprises:

receiving the at least one uplink lower-layer over an uplink channel from an uplink user device;

converting the at least one uplink lower-layer to the at least one uplink higher-layer packet; and

transmitting the at least one uplink higher-layer packet to an uplink base station server.

In an embodiment, converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises segmenting the at least one downlink

higher-layer packet into a plurality of downlink lower-layer packets according to a Radio Link Control (RLC) protocol.

In an embodiment, converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises concatenating a plurality of downlink higher-layer packets into the at least one downlink lower-layer packet according to a Radio Link Control (RLC) protocol.

In an embodiment, converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises reassembling the at least one downlink higher-layer packet as the at least one downlink lower-layer packet according to a Radio Link Control (RLC) protocol.

In an embodiment, the Radio Link Control (RLC) protocol conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard.

The present invention also provides a base station server comprising:

at least one downlink packet transmitter, each downlink packet transmitter that:

receives at least one downlink higher-layer packet;

converts the at least one downlink higher-layer packet to at least one downlink lower-layer packet; and

transmits the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device; and

at least one uplink packet receiver, each uplink packet receiver that:

receives from an uplink base station client at least one uplink higher-layer packet converted by the uplink base station client from at least one uplink lower-layer packet received by the uplink base station client over an uplink channel from an uplink user device; and

processes the at least one uplink higher-layer packet.

In an embodiment, the base station server comprises a plurality of uplink packet receivers, each uplink packet receiver being associated with a respective one of the plurality of uplink base station clients.

In an embodiment, the base station server comprises a plurality of downlink packet transmitters, each downlink packet transmitter being associated with a respective one of the plurality of downlink base station clients.

In an embodiment, the uplink packet receiver processes the at least one uplink higher-layer packet, by transmitting the at least one higher-layer packet to another one of the at least one downlink packet transmitter.

In an embodiment, the uplink packet receiver processes the at least one uplink higher-layer packet, by transmitting the at least one higher-layer packet to another base station server.

The present invention also provides a system for de-compressing packets, comprising:

a base station client performs a de-compression of a packet comprising a header and a payload; and

a base station server further processes the de-compressed packet,

wherein the base station client performs the de-compression of the packet by:

receiving the packet over a channel from a user device;

de-compressing the header of the packet; and

transmitting the de-compressed header and the payload of the packet as the de-compressed packet to the base station server for further processing.

In an embodiment, the base station server is located at a first site, and the base station client is located at a second site remote from the first site.

In an embodiment, the channel is an uplink radio channel.

In an embodiment, the dez-compressed header is a header of an Internet Protocol (IP) packet.

In an embodiment, the header is a header of a Service Data Unit (SDU) that conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard.

In an embodiment, the system further comprises a plurality of base station clients, and wherein the base station server receives a de-compressed packet from each base station client.

In an embodiment, the base station server is connected to each base station client via a respective one of a plurality of optical fibre links.

In an embodiment, the base station server is connected to each base station client via a respective one of a plurality of Ethernet connections.

The present invention also provides a method of de-compressing packets, comprising:

performing at a base station client a de-compression of a packet comprising a header and a payload; and

further processing the de-compressed packet at a base station server,

wherein performing the de-compression of the packet at the base station client comprises:

receiving the packet over a channel from a user device;

de-compressing the header of the packet; and

transmitting the de-compressed header and the payload of the packet as the de-compressed packet to the base station server for further processing.

In an embodiment, the header is de-compressed according to a Packet Data Convergence Protocol (PDCP).

In an embodiment, the Packet Data Convergence Protocol (PDCP) conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard.

The present invention also provides a base station server comprising:

at least one packet receiver, each packet receiver that:

receives from a base station client a packet de-compressed by the base station client from a compressed packet received by the base station client over a channel from a user device; and

further processes the packet,

wherein the compressed packet comprises a compressed header and a payload, and the packet comprises a header de-compressed from the header of the compressed packet and the payload of the compressed packet.

In an embodiment, the base station server comprises a plurality of packet receivers, each packet receiver being associated with a respective one of a plurality of base station clients.

In an embodiment, each packet receiver further processes the packet, by transmitting the packet to another base station server.

In an embodiment, the base station server further comprises at least one downlink packet transmitter, each downlink packet transmitter that:

receives a downlink packet comprising a header and a downlink payload;

compresses the header of the downlink packet; and

transmits the compressed header and the downlink payload of the downlink packet as the compressed downlink packet to a downlink base station client for transmission over a downlink channel to a downlink user device.

BRIEF DESCRIPTION OF DRAWINGS

In order that the invention may be more clearly ascertained, embodiments of the invention will be described, by way of example, with reference to the accompanying drawings in which:

FIG. **1** is a schematic diagram of an embodiment of the system comprising a base station server and a plurality of base station clients;

FIG. **2** is a schematic diagram of the logical components of the system;

FIG. **3** is a schematic diagram of the physical components of the base station server;

FIG. **4** is a schematic diagram of the physical components of a base station client;

FIG. **5** is a schematic diagram of some of the functional components of the base station server and the base station client;

FIG. **6** is a flowchart of an embodiment of a method of operation performed by the base station client of FIG. **5**;

FIG. **7** is a flowchart of an embodiment of a method of operation performed by the base station server of FIG. **5**;

FIG. **8** is a schematic diagram of the other functional components of the base station server and the functional components of the base station client;

FIG. **9** is a flowchart illustrating in greater detail the steps of FIG. **6** performed by the base station client of FIG. **8**;

FIG. **10** is a flowchart illustrating in greater detail the steps of FIG. **7** performed by the base station server of FIG. **8**;

FIG. **11** is schematic diagram of the other functional components of the base station server of an alternative embodiment of the system, and the functional components of the base station client of the alternative embodiment of the system;

FIG. **12** is a flowchart illustrating in greater detail the steps of FIG. **6** performed by the base station client of the alternative embodiment of the system of FIG. **11**;

FIG. **13** is a flowchart illustrating in greater detail the steps of FIG. **7** performed by the base station server of the alternative embodiment of the system of FIG. **11**;

FIGS. **14**A and **14**B are two flowcharts illustrating an embodiment of a method performed by the base station client and the base station server of the system; and

FIGS. **15**A and **15**B are two flowcharts illustrating, respectively, an embodiment of a method of compressing packets and an embodiment of a method of decompressing packets.

DETAILED DESCRIPTION

Referring to the accompanying drawings, there is described a system **1**, **5**, **111** for converting between higher-layer packets and lower-layer packets, for example, between Radio Link Control (RLC) Service Data Units (SDUs) and RLC Packet Data Units (PDUs) of the 3GPP LTE standard. The system **1**, **5**, **111** comprises a base station client **11***a*, **12***a*, **13***a*, **115** that receives uplink lower-layer packets from an uplink user device such as an uplink User Equipment (UE) (that is, a UE making uplink transmissions) conforming to the 3GPP LTE standard. The system **1**, **5**, **111** also comprises a base station server **10** that receives downlink high-layer packets for transmission to a downlink user device such as a downlink UE (that is, a UE making downlink transmissions). The base station server **10** is performs a conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet, and the base station client **11***a*, **12***a*, **13***a*, **115** is performs a conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet. Thus, the system **1**, **5**, **111** is advantageous in that downlink packet conversions for multiple downlink UEs can be cost-effectively centralized at the base station server **10** without compromising the performance (for example, delay or latency performance) of the system **1**, **5**, **111** to perform uplink packet conversions for uplink UEs.

Persons skilled in the art will appreciate that the term "uplink" refers to the flow of data/packets from a UE to an eNodeB, and the term "downlink" refers to the flow of data/packets from an eNodeB to a UE.

Radio Protocol Architecture

The radio protocol architecture of the 3GPP LTE standard may be separated into a user plane architecture (the user plane) and a control plane architecture (the control plane). The user plane specifies radio protocol layers (and radio protocol sub-layers) in respect of user data (or user traffic). The control plane specifies radio protocol layers (and radio protocol sub-layers) in respect of control/signalling information. The radio protocol layers (and radio protocol sub-layers) of the user plane architecture and the control plane architecture include:

- Layer 1 (L1 layer)
  - Physical (PHY) sub-layer
- Layer 2 (L2 layer)
  - Medium Access Control (MAC) sub-layer
  - Radio Link Control (RLC) sub-layer
  - Packet Data Convergence Protocol (PDCP) sub-layer
- Layer 3 (L3 layer)
  - a Radio Resource Control (RRC) sub-layer

The operations that may be performed at the layers (and sub-layers) of the user plane and the control plane are specified in the 3GPP LTE standard. For example, many of the operations performed by an eNodeB at the layers (sub-layers) of the L2 layer may be found in Technical Specification 36.300 of the 3GPP LTE standard.

General Construction of the System

FIG. **1** is a schematic diagram of an embodiment of the system **1**. The system **1** conforms to the 3GPP LTE standard, and is based on a Cloud-Random Access Network (C-RAN) arrangement where baseband processing conventionally performed by a conventional eNodeB is split/distributed between a base station server **10** (also referred to as a base station hotel) and a base station client **11***a*, **12***a*, **13***a* (also referred to as cell site equipment or a Remote Radio Head Unit (RHU)).

The system **1** comprises a base station server **10** and three base station clients **11***a*, **12***a*, **13***a*. Persons skilled in the art will appreciate that the system **1** may include more than one base station server **10** and/or one, two or more than three base station clients **11***a*, **12***a*, **13***a*.

Each base station client **11***a*, **12***a*, **13***a* is located at a respective one of a plurality of cell sites (or antenna towers) **11***b*, **12***b*, **13***b* located remotely from the location of the base station server **10**, and is connected to the base station server **10** such that one or more packets (for example, one or more RLC SDUs received from a UE) may be transmitted from the base station client **11***a*, **12***a*, **13***a* to another base station client **11***a*, **12***a*, **13***a* via the base station server **10**. Each base station client **11***a*, **12***a*, **13***a* is connected to the base station server **10** via an optical fibre link. Persons skilled in the art will appreciate that one or more of the base station clients **11***a*, **12***a*, **13***a* may alternatively be connected to the base station server **10** via a different type of link such as a high-speed wireless link.

It is envisaged that the base station server **10** may be connected to other base station servers or conventional eNodeBs such that one or more packets (for example, one or more RLC SDUs received from a base station client **11***a*, **12***a*, **13***a*) may be transmitted from the base station server **10** to another base station server or conventional eNodeB. The base station server **10** may be connected to other base station servers or conventional eNodeBs via a core network (such as an Evolved Packet Core (EPC)), and that the base station server **10** may be connected to the core network via a connection

point (such as a General Packet Radio Service (GPRS) Tunnelling Protocol-User plane (GTP-U) Tunnel end point) at the core network. Also, it is envisaged that the system **1** may support multiple bands and be scaled by increasing the number of base station clients **11***a*, **12***a*, **13***a* and the capacity of the base station server **10**, for example, by increasing the number of baseband processing units implemented by the base station server **10**.

FIG. **2** is a schematic diagram of the logical components of the system **1**. The base station server **10** comprises a plurality of clusters of Baseband processing Units (BBUs) **21**. The BBUs **21** of each cluster of BBUs are connected to a respective cluster packet scheduler **22**. Each cluster packet scheduler **22** can control each of the BBUs **21** connected to the cluster packet scheduler **22** to coordinate and/or manage packet scheduling and/or resource allocations. Also, the BBUs **21** of each cluster of BBUs may be jointly coordinated by a corresponding cluster packet scheduler **22**.

In this embodiment, the base band server **10** is implemented on a Virtual Cloud Platform (VCP), and each cluster packet scheduler **22** is connected to a VCP packet scheduler **23**. All of the BBUs of the system **1** may be jointly coordinated by the VCP packet scheduler **23**. Each BBU **21** is connected to a corresponding base station client **11***a*, **12***a*, **13***a* via a corresponding cluster packet scheduler **22**, and the VCP packet scheduler **23**.

Each BBU **21** comprises a RRC processing entity **211**, a PDCP processing entity **212** and a RLC processing entity **213**. Each BBU **21** is associated with a corresponding MAC/PHY processing entity **214**. It is envisaged that the baseband processing conventionally performed by a conventional eNodeB can be performed by a base station client **11***a*, **12***a*, **13***a*, a corresponding BBU **21**, a corresponding cluster packet scheduler **22**, a corresponding MAC/PHY processing entity **214** and the VCP packet scheduler **23** of the system **1**.

FIG. **3** is a schematic diagram of the physical components of the VCP **3** implementing the base station server **10**. The VCP **3** includes a processor unit **31**, a memory unit **32**, an input/output interface **33** and a power management unit **34**. The processor unit **31** is logically or electrically connected to the memory unit **32**, the input/output interface **33** and the power management unit **34**. It is envisaged that the VCP **3** may be a blade server, and the processor unit **31** may be a multi-core processor. The memory unit **32** may include static memory storage devices and dynamic memory storage devices.

The processor unit **31** is configured to implement (or execute) a number of software modules based on program code and/or data stored in the memory unit **32**. For example, the memory unit **32** stores program code for implementing software modules corresponding to the RRC processing entity **211**, the PDCP processing entity **212**, the RLC processing entity **213**, the MAC/PHY processing **214**, the cluster packet scheduler **22** and the VCP packet scheduler entity **23**. Persons skilled in the art will appreciate that one or more of the software modules could alternatively be implemented in some other way, for example, by one or more dedicated circuits.

The input/output interface **33** is an interface for connecting each BBU **21** to a corresponding base station client **11***a*, **12***a*, **13***a*. The power management unit **34** includes a power supply (not shown) for providing electrical power to the VCP **3** and management logics (not shown) for controlling the supply of power to the VCP **3**.

FIG. **4** is a schematic diagram of the physical components of a base station client **11***a*, **12***a*, **13***a*. Each base station client **11***a*, **12***a*, **13***a* includes a processor unit **41**, a memory unit **42**, an input/output interface **43**, a power management unit **44**, and a Remote Radio Head (RRH) **45**. The RRH **45** comprises Radio Frequency (RF) circuitry for transmitting and/or receiving RF signals conforming to the 3GPP LTE standard. It is envisaged that the RRH **45** may include an antenna (not shown) and RF signal processing components (not shown) such as, but not limited to, a Digital-to-Analogue signal converter (DAC), an Analogue-to-Digital signal converter (ADC), an oscillation signal generator, a modulator, a demodulator, a power amplifier, and a bandpass filter.

The processor unit **41** is logically or electrically connected to the memory unit **42**, the input/output interface **43**, the power management unit **44**, and the RRH **45**. It is envisaged that the processor unit **41** may be a multi-core processor. The memory unit **42** may include static memory storage devices and dynamic memory storage devices. The processor unit **41** is configured to implement (or execute) a number of software modules based on program code and/or data stored in the memory unit **42**. For example, the memory unit **42** may store program code for implementing software modules corresponding to a MAC/PHY processing entity corresponding to the MAC/PHY processing entity **214** of FIG. **2**. Persons skilled in the art will appreciate that one or more of the software modules could alternatively be implemented in some other way, for example, by one or more dedicated circuits.

The input/output interface **43** is an interface for connecting the base station client **11***a*, **12***a*, **13***a* to the base station server **10**. The power management unit **44** includes a power supply (not shown) for supplying electrical power to the base station client **11***a*, **12***a*, **13***a* and management logics (not shown) for controlling the electrical power supply to the base station client **11***a*, **12***a*, **13***a*.

Further Details of the System

FIG. **5** is a schematic diagram of the functional components (shared functional components) implemented on the VCP **3** to manage the BBUs **21** of the base station server **10**. In FIG. **5**, only part **5** of the system **1** (more specifically, only two of the BBUs **541**, **551** and two of the base station clients **11***a*, **12***a*) is illustrated. In FIG. **5**, the baseband processing conventionally performed by a conventional eNodeB is performed by an eNodeB **54**, **55** comprising a BBU **541** and a corresponding base station client **11***a*, **12***a*.

The VCP **3** comprises a carrier Ethernet Internet Protocol (IP) interface in the form of a Giga-bit Ethernet interface **53**. Each BBU **541**, **551** is connected to a corresponding base station client **11***a*, **12***a* via the Giga-bit Ethernet interface **53** and a Giga-bit Ethernet interface **401**, **552** of the base station client **11***a*, **12***a*.

The VCP **3** also includes a Radio Resource Management (RRM) entity **52** including: a measurement control entity **521**, a radio bearer admission control entity **522**, a load balancing entity **523**, a mobility control entity **524**, a radio bearer control entity **525**, a Self-Organizing Network (SON) entity **526** and a cell coordination scheduler **527**. Each BBU **541**, **551** is connected to the measurement control entity **521**, the radio bearer admission control entity **522**, the load balancing entity **523**, the mobility control entity **524**, the radio bearer control entity **525** and the SON entity **526** via the cell coordination scheduler **527**. The cell coordination scheduler **527** performs radio resource allocation and packet scheduling for each BBU **541**, **551** and corresponding base station client **11***a*, **12***a*. The cell coordination scheduler **527** implements the cluster packet scheduler **22** and the VCP packet scheduler **23** of FIG. **2**.

The measurement control entity **521** controls broadcasting or transmission of dedicated control/signalling information

such that a UE in data communication with a BBU **541**, **551** of the VCP **3** can, according to the control/signalling information, perform measurements for intra/inter-frequency mobility. The radio bearer admission control entity **522** determines whether a new radio bearer can be accepted by the system **1**, **5**, according to currently available radio resource (such as the currently available radio resource of the serving cell base station client **11***a*, **12***a*). The load balancing entity **523** perform load balancing algorithms (such as intra-frequency, inter-frequency or inter-Radio Access Technology (RAT) algorithms for performing handovers). The mobility control entity **524** performs determinations related to mobility of UEs, for example, during handover and Tracking Area Update (TAU). The radio bearer control entity **525** establishes, maintains, and releases radio bearers, and to configure radio resources associated with radio bearers. The SON entity **526** exchanges information (such as an Automatic Neighbour Relation function) between neighbouring eNodeBs **54**, **55**. It is also envisaged that the SON entity **526** may perform automatic Physical Cell Identity (PCI) selection, dynamic configuration of X2/S1 interfaces, Random Access Channel (RACH) parameter optimization, and mobility parameter optimization.

The VCP **3** also includes an Operation Administration Monitoring (OAM) entity **51**. The OAM entity **51** is logically connected to the RRM entity **52**, each BBU **541**, **551** and the Giga-bit Ethernet interface **53**. The OAM entity **51** performs OAM/control operations. In particular, the OAM entity **51** performs OAM/control of a MAC sub-layer processing entity (not shown) and a PHY sub-layer processing entity (not shown). It is envisaged that such OAM/control typically involves relevant MAC and PHY sub-layers configuration information. It is envisaged that the OAM entity **51** may interact with the RRM entity **52** and directly transmit/receive control/signalling information to/from a RRC sub-layer processing entity (not shown) of each BBU **541**, **551**. Also, the OAM entity **51** may transmit/receive, over the Giga-bit Ethernet interface **53**, OAM/control and configuration information to/from a corresponding OAM entity (not shown) of each base station client **11***a*, **12***a*.

FIG. **8** is a schematic diagram of the functional components of a BBU **541** and a base station client **11***a* of the embodiment of the system **1**, **5** of FIG. **5**. In FIG. **8**, some of the shared functional components (such as the measurement control entity **521**, the radio bearer admission control entity **522**, the load balancing entity **523**, the mobility control entity **524**, the radio bearer control entity **525** and the SON entity **526** of the RRM **52**) of the system **1**, **5** are not shown.

The BBU **541** comprises a RRC processing entity **211**, a PDCP processing entity **212**, a RLC processing entity **213**, and a MAC-Packet Scheduler (MAC-PS) processing entity **215**. The RRC processing entity **211** is logically connected to the cell coordination scheduler **527** and the OAM entity **51** of the VCP **3**. The RRC processing entity **211**, the RLC processing entity **213** and the MAC-PS processing entity **215** are logically connected to the base station client **11***a* via the Giga-bit Ethernet Interface **53** of the VCP **3**.

The base station client **11***a* comprises a security entity **403**, a MAC downlink (DL) processing entity **404**, a HARQ entity **405**, a RLC processing entity **407**, a PDCP processing entity **408**, a PHY layer processing entity **409**, a RF unit **410**, an antenna unit **411**, an OAM processing entity **402** and a MAC uplink (UL) processing entity **406**. The MAC (DL) processing entity **404**, the PHY processing entity **409**, and the RF unit **410** are logically connected to the OAM processing entity **402** of the base station client **11***a*. The security entity **403** is logically connected to the RLC processing entity **213** of the BBU **541**. The MAC (DL) processing entity **404** is logically connected to the MAC-PS processing entity **215** of the BBU **541**. The PHY processing entity **409** is logically connected to the MAC-PS processing entity **215** of the BBU **541**. The PDCP processing entity **408** is logically connected to the RRC processing entity **211** of the BBU **541**.

The RRC processing entity **211** of the BBU **541** is responsible for performing RRC sub-layer processing in both the uplink and the downlink. Persons skilled in the art will appreciate the RRC sub-layer processing may include processing of control/signalling information in the control plane and/or of data in the user plane.

The PHY layer processing entity **409**, the RF unit **410** and the antenna unit **411** are responsible for performing PHY layer signal processing such as RF signal processing in both the uplink and the downlink. Together, the PHY processing entity **409**, the RF unit **410** and the antenna unit **411** form the RRH **45** of FIG. **4**.

The OAM processing entity **402** of the base station client **11***a* passes OAM/control and configuration information to the MAC (DL) processing entity **404**, the PHY processing entity **409**, and the RF unit **410**. It is envisaged that OAM/control and configuration information may be communicated between the OAM processing entity **51** of the VCP **3** and the OAM processing entity **402** of the base station client **11***a* in both the uplink and the downlink.

PDCP, RLC and MAC sub-layer processing is split between the BBU **541** and the base station client **11***a* such that processing that is less latency critical is performed by the BBU **541** and processing that is more latency critical is performed by the base station client **11***a*.

In the downlink, the PDCP processing entity **212**, the RLC processing entity **213**, and the MAC-PS processing entity **215** of the BBU **541** and the MAC (DL) processing entity **404** and the HARQ processing entity **405** of the base station client **11***a* are responsible for processing control/signalling information in the control plane and/or data in the user plane.

The PDCP processing entity **212** of the BBU **541** is responsible for performing downlink PDCP sub-layer processing. For example, the PDCP processing entity **212** of the BBU **541** receives information on radio bearers, and map the information onto logical channels in the form of at least one RLC PDU. In particular, the PDCP processing entity **212** of the BBU **541** receives one or more packets (such as Internet Protocol (IP) packets from, for example, a connection point at the core network), perform Robust Header Compression (ROHC) of the header of one or more of the received data packets, and transmit the compressed data packets to the RLC processing entity of the BBU **541** for RLC sub-layer processing.

The RLC processing entity **213** of the BBU **541** is responsible for performing downlink RLC sub-layer processing. More specifically, the RLC processing entity **213** of the BBU **541** performs a conversion of at least one RLC SDU to at least one RLC PDU, by receiving the at least one RLC SDU from the PDCP processing entity **212**, converting the at least one RLC SDU to at least one RLC PDU (for example, by segmenting a RLC SDU into a plurality of RLC PDUs or concatenating a plurality of RLC SDUs into one RLC PDU), and transmitting the at least one RLC PDU to the base station client **11***a*.

Downlink MAC sub-layer processing is performed by two separate parts of a split downlink MAC processing entity comprising the MAC-PS processing entity **215** of the BBU **541** and the MAC downlink (DL) processing entity **404** of the base station client **11***a*. The MAC-PS processing entity **215** of the BBU **541** is responsible for determining downlink MAC

sub-layer scheduling policies. In particular, the MAC-PS processing entity **215** of the BBU **541** generates, for each Transmission Time Interval (TTI), Resource Block (RB) resource allocations and a Control Format Indicator (CFI), and transmits the generated RB resource allocations and CFI to the base station client **11***a*. Scheduling control and coordination information may be transmitted from the cell coordination scheduler **527** of the BBU **541** to the MAC-PS processing entity **215** of the BBU **541**.

The MAC (DL) processing entity **404** of the base station client **11***a* is responsible for performing (or implementing) the downlink MAC sub-layer scheduling policies determined by MAC-PS processing entity **215** of the BBU **541**. For example, the MAC (DL) processing entity **404** of the base station client **11***a* controls transmissions or retransmissions of the at least one RLC PDU from the RLC processing entity **213** based on the RB resource allocations and CFI generated by the MAC-PS processing entity **215** of the BBU **541**. That is, the MAC (DL) processing entity **404** controls for each TTI whether or not the base station client **11***a* makes a new RLC PDU transmission or to send a retransmission of RLC PDU in the TTI. It is envisaged that downlink MAC sub-layer processing is performed by the MAC (DL) processing entity **404** for all UEs within radio service coverage of the base station client **11***a*.

The security entity **403** of the base station client **11***a* is responsible for integrity of transmitted or received control/signalling information in the control plane and/or data in the user plane. For example, the security entity **403** encrypts the at least one RLC PDU generated by the RLC processing entity **213** of the BBU **541**, before transmission or retransmission of the encrypted RLC PDU.

The HARQ processing entity **405** of the base station client **11***a* is responsible for informing the MAC (DL) processing entity **404** of the base station client **11***a* whether or not a transmission to a UE has been successfully received by the UE in the downlink. In particular, the HARQ processing entity **405** of the base station client **11***a* transmits any ACK/NACK received from the UE to the MAC (DL) processing entity **404** of the base station client **11***a* in the downlink. By implementing the HARQ processing entity **405** together with the MAC (DL) processing entity **404** and the PHY layer processing entity **409** at the base station client **11***a*, it is expected that RLC PDUs requiring retransmission can be retransmitted directly from the base station client **11***a* without first being transmitted from the BBU **541** to the base station client **11***a*.

It is envisaged that the HARQ processing entity **405** of the base station client **11***a* may manage up to 8 HARQ processes per UE. Also, it is envisaged that communications between the MAC (DL) processing entity **404** and the HARQ processing entity **405** may include Downlink Control Information (DCI) related to Transport Blocks (TBs) to be transmitted to a UE in a TTI. Examples of DCI include HARQ process numbers and New Data Indicators (NDIs). Also, the DCI may alternatively or additionally include Modulation and Coding Scheme (MCS) information, Redundancy Version (RV) information, RB allocations information and/or antenna mapping information for L1 layer coding and modulation.

Turning to the uplink, the HARQ processing entity **405**, the MAC (UL) processing entity **406**, the RLC processing entity **407**, and the PDCP processing entity **408** of the base station client **11***a* are responsible for processing control/signalling information in the control plane and/or data in the user plane.

The HARQ processing entity **405** of the base station client **11***a* is responsible for deriving one or more Transport Blocks (TBs) from RF signals received by the PHY processing entity **409** of the base station client **11***a*. The output of the HARQ processing entity **405** comprises TBs which have been correctly received. Persons skilled in the art will appreciate that TBs may be received out of sequence by the base station client **11***a* due to retransmissions. In addition to the correctly received TBs, the HARQ processing entity **405** delivers Cyclic Redundancy Checks (CRCs) and ACKs/NACKs to the MAC (UL) processing entity **406** for transmission to a UE. It is envisaged that such information may also be provided to the MAC (DL) processing entity **404** for performing downlink processing.

The MAC (UL) processing entity **406** of the base station client **11***a* generates at least one RLC PDU from the TBs output by the HARQ processing entity **405** of the base station client **11***a*. The MAC (UL) processing entity **406** of the base station client **11***a* is also generates information such as received CQI reports, acknowledgements (ACKs)/negative ACKs (NACKs), RACH Preambles, MAC control element (CE) information, and to transmit the generated information to the BBU **541**. It is envisaged that the information may be generated independently by the MAC (UL) processing entity **406** of the base station client **11***a* or together in conjunction with the PHY processing entity **409** of the base station client **11***a*. It is envisaged that the RB resource allocations and CFI generated for each TTI by the MAC-PS processing entity **215** of the BBU **541** may be based on at least part of the information generated by the MAC (UL) processing entity **406** and the PHY processing entity **409** of the BBU **541**. Also,

The RLC processing entity **407** of the base station client **11***a* is responsible for performing uplink RLC sub-layer processing. In particular, the RLC processing entity **407** of the base station client **11***a* performs a conversion of the at least one RLC PDU generated by the MAC (UL) processing entity **406** of the base station client **11***a* to at least one RLC SDU, by receiving the at least one RLC PDU from the MAC (UL) processing entity **406**, converting the at least one RLC PDU to at least one RLC SDU (for example, by reassembling a plurality of RLC PDUs into a RLC SDU), and transmitting the at least one RLC SDU to the PDCP processing entity **408** of the base station client **11***a*.

The PDCP processing entity **408** of the base station client **11***a* is responsible for performing uplink PDCP sub-layer processing. In particular, the PDCP processing entity **408** of the base station client **11***a* performs a de-compression of one or more of the SDUs received from the RLC processing entity **407** of the base station client **11***a*, and to forward the SDU or SDUs (including those that are de-compressed by the PDCP processing entity **408**) received from the RLC processing entity **407** of the base station client **11***a* to an appropriate entity. More specifically, the PDCP processing entity **408** de-compresses the header of each of the one or more SDUs according to ROHC (that is, the Robust Header Compression framework), and forwards (i) the de-compressed header of each one of the SDUs together with (ii) the corresponding payload to the appropriate entity. It is envisaged that packets received from a UE in the user plane may be processed and then forwarded by the PDCP processing entity **408** of the base station client **11***a* to an appropriate entity such as a connection point at the core network, and packets received from a UE in the control plane may be forwarded by the PDCP processing entity **408** of the base station client **11***a* to an appropriate entity such as the RRC processing entity **211** of the BBU **541**.

FIG. **11** is schematic diagram of the functional components of the BBU **114** and the base station client **115** of an alternative embodiment of the system **111**. This alternative embodiment is almost the same as the embodiment of FIG. **8**, except that encryption and decryption of RLC PDUs is performed by

a PDCP processing entity **220** of the BBU **114** of the system **111** (as opposed to a separate security entity **403** at a base station client **11***a* in the embodiment of FIG. **8**).

FIGS. **15**A and **15**B are two flowcharts **1500**, **1502** illustrating respectively an embodiment of a method of compressing packets, and an embodiment of a method of de-compressing packets. More specifically, the flowchart **1500** of FIG. **15**A illustrates the steps to compress IP packets received from a connection point at the core network in the downlink, and the flowchart **1502** of FIG. **15**B illustrates the steps to de-compress compressed IP packets received from the RLC processing entity **407** of the base station client **11***a*, **12***a*, **13***a* in the uplink.

Beginning first with the flowchart **1500** of FIG. **15**A, in step **1520**, the PDCP processing entity **212** implemented on the VCP **3** of the base station server **10** receives one or more IP packets from the connection point to the core network. Each of the IP packets comprises an IP header and a payload.

In step **1560**, the PDCP processing entity **212** performs downlink PDCP processing according to the PDCP protocol specified in the 3GPP LTE standard. In particular, in step **1568**, the PDCP processing entity **212** compresses the IP header of each of one or more of the received IP packets, according to the ROHC framework specified in the 3GPP LTE standard.

In step **1580**, the PDCP processing entity **212** transmits the compressed and uncompressed IP packets (that is, the received IP packets comprising IP headers compressed by the PDCP processing entity **212**, and the received IP packets comprising IP headers that are not compressed by the PDCP processing entity **212**) to the RLC processing entity **213** implemented on the VCP **3** of the base station server **10** for further processing.

Turning to the flowchart **1502** of FIG. **15**B, in step **1510**, the PDCP processing entity **408** of the base station client **11***a*, **12***a*, **13***a* receives one or more compressed IP packets. Each one of the compressed IP packet is a RLC SDU transmitted from an uplink user device to the base station client **11***a*, **12***a*, **13***a* over an uplink radio channel specified in the 3GPP LTE standard. Each one of the compressed IP packet comprises a compressed IP header and a payload.

In step **1530**, the base station client **11***a*, **12***a*, **13***a* performs uplink PDCP processing on the compressed IP packets received from the uplink user device, according to the PDCP protocol specified in the 3GPP LTE standard. In particular, the PDCP processing entity **408** de-compresses the compressed IP header of each of the compressed IP packets in step **1538**.

In step **1590**, the base station client **11***a*, **12***a*, **13***a* transmits (i) the IP header (now de-compressed by the PDCP processing entity **408**) of each of the IP packets together with (ii) the corresponding payload to the base station server **10** via the Giga-Bit Ethernet interface **401** of the base station client **11***a*, **12***a*, **13***a* for further processing (for example, for the base station server **10** to transmit to the connection point at the core network).

FIGS. **14**A and **14**B are two flowcharts **1400**, **1402** illustrating an embodiment of a method of converting between RLC SDUs and RLC PDUs performed by a base station client **11***a*, **12***a*, **13***a* and a base station server **10** of the system **1**, **5** of FIGS. **1** to **5** and **8**. More specifically, the flowchart **1400** of FIG. **14**A illustrates the steps performed by the base station server **10** to perform a conversion of at least one RLC SDU to at least one RLC PDU in the downlink, and flowchart **1402** of FIG. **14**B illustrates the steps performed by the base station client **11***a*, **12***a* **13***a* to perform a conversion of at least one RLC PDU to at least one RLC SDU in the uplink.

Beginning first with the flowchart **1400** of FIG. **14**A, in step **1410**, the RLC processing entity **213** implemented on the VCP **3** of the base station server **10** receives one or more RLC SDUs from the PDCP processing entity **212** implemented on the VCP **3**.

In step **1430**, the RLC processing entity **213** converts the received RLC SDUs into one or more RLC PDUs according to the RLC protocol specified in the 3GPP LTE standard. For example, the RLC processing entity **213** may convert a received RLC SDU into a plurality of RLC PDUs, by segmenting the received RLC SDU into the plurality of RLC PDUs in step **1433**. In another example, the RLC processing entity **213** may convert a plurality of received RLC SDUs into a RLC PDU, by concatenating the plurality of received RLC SDUs into the RLC PDU in step **1439**.

In step **1490**, the RLC processing entity **213** transmits the RLC PDUs to the base station client **11***a*, **12***a*, **13***a* via the Giga-Bit Ethernet interface **53** of the base station server **10** for transmission over a radio channel to a UE in the downlink. Upon receiving the RLC PDUs from the base station server **10**, the base station client **11***a*, **12***a*, **13***a* then transmits the RLC PDUs over the radio channel to the UE. As indicated above, processing (such as encryption performed by the security entity **403** of the base station client **11***a*, **12***a*, **13***a*) of the RLC PDUs may be performed by the base station client **11***a*, **12***a*, **13***a* on the RLC PDUs received from the base station server **10**, before the RLC PDUs is transmitted by base station client **11***a*, **12***a*, **13***a* over the radio channel to the UE.

Turning to the flowchart **1402** of FIG. **14**B, in step **1420**, the RLC processing entity **407** of the base station client **11***a*, **12***a*, **13***a* receives one or more RLC PDUs from a UE via the MAC (UL) processing entity **406** and the PHY processing entity **409** of the base station client **11***a*, **12***a*, **13***a*.

In step **1460**, the RLC processing entity **407** converts the received RLC PDUs into one or more RLC SDUs. More specifically, the RLC processing entity **407** converts the received RLC PDUs into the RLC SDUs, by reassembling the received RLC PDUs into the RLC SDUs according to the RLC protocol specified in the 3GPP LTE standard in step **1468**.

In step **1480**, the RLC processing entity **407** transmits the RLC SDUs to the PDCP processing entity **408** of the base station client **11***a*, **12***a*, **13***a* for PDCP sub-layer processing (such as ROHC decompression), before the RLC SDUs is transmitted by the base station client **11***a*, **12***a*, **13***a* to the base station server **10** via the Giga-Bit Ethernet interface **401** of the base station client **11***a*, **12***a*, **13***a*.

FIG. **6** is a flowchart of an embodiment of a method of operation performed by a base station client **11***a*, **12***a*, **13***a* of the embodiment of the system **1**, **5** of FIG. **5**.

In step **S61**, the base station client **11***a*, **12***a*, **13***a* of the system **5** performs the following steps in respect of the downlink: receiving one or more RLC PDUs and radio resource scheduling information for a TTI of a pre-configured duration over the Giga-Bit Ethernet interface **401**, **552** of the base station client **11***a*, **12***a*, **13***a* from the VCP **3**, converting the RLC PDUs into RF signals that are suitable for transmission to one or more UEs according to the received radio resource scheduling information, and transmitting the RF signals to the one or more UEs. The conversion of the RLC PDUs into the RF signals may include performing downlink MAC sub-layer operations and downlink PHY sub-layer operations.

In step **S62**, the base station client **11***a*, **12***a*, **13***a* performs the following steps in respect of the uplink: receiving RF signals from one or more UEs, transmitting information required for the MAC-PS processing entity **215** of the VCP **3** over the Giga-Bit Ethernet interface **401**, **552** of the base

station client **11***a*, **12***a*, **13***a*, converting the received RF signals into information on radio bearers, and transmitting the information on the radio bearers as packet signals over the Giga-Bit Ethernet interface **401**, **552** to the VCP **3**. The conversion of the received RF signals into the information on the radio bearers may include performing uplink MAC sub-layer operations, uplink RLC sub-layer operations and uplink PDCP sub-layer operations.

Also, in step S**63**, an OAM entity of the base station client **11***a* transmits/receives OAM/control and configuration information to/from a corresponding OAM entity **51** of the VCP **3** the uplink.

FIG. **7** is a flowchart of an embodiment of a method of operation performed by a BBU **541**, **551** of the system **5** of FIG. **5**.

In step S**71**, the BBU **541**, **551** performs the following steps in respect of the downlink: receiving, for one or more UEs under radio service coverage of a corresponding base station client **11***a*, **12***a*, **13***a*, scheduling control and coordination information of the UEs from the cell coordination scheduler **527**.

In step S**72**, the BBU **541**, **551** performs the following steps in respect of the downlink: receiving user-plane information on radio bearers over a networking interface from a connection point at a core network, converting the user-plane information on radio bearers into one or more RLC PDUs, and transmitting the RLC PDUs to a corresponding base station client **11***a*, **12***a*, **13***a* over the Giga-Bit Ethernet interface **401**, **552** of the VCP **3**. The conversion of the user-plane information on radio bearers into the RLC PDUs may include performing downlink PDCP sub-layer operations and downlink RLC sub-layer operations.

In step S**73**, the BBU **541**, **551** performs the following steps in respect of the downlink: generating, radio resource scheduling information for a TTI of a pre-configured duration, and transmitting the radio resource scheduling information for the TTI to a corresponding base station client **11***a*, **12***a*, **13***a* over the Giga-Bit Ethernet interface **401**, **552** of the VCP **3**.

In step S**74**, the BBU **541**, **551** performs the following steps in respect of the downlink: receiving information required for MAC sub-layer downlink scheduling from the corresponding base station client **11***a* over the Giga-Bit Ethernet interface **401**, **552** of the VCP **3**.

In step S**75**, the BBU **541**, **551** performs the following steps in respect of the downlink: receiving information on radio bearers as packet signals from the corresponding base station client **11***a*, **12***a*, **13***a* over the Giga-Bit Ethernet interface **401**, **552** of the VCP **3**.

In step S**76**, the OAM entity **51** of the VCP **3** transmits/receives OAM/control and configuration information to/from corresponding OAM entities of the base station clients **11***a*, **12***a*, **13***a*.

It is envisaged that the steps of the methods of operation illustrated in FIGS. **6** and **7** may be implemented by either the embodiment of the system **1**, **5** shown in FIG. **8** or the alternative embodiment of the system **1**, **111** shown in FIG. **11**.

FIG. **9** is a flowchart illustrating in greater detail the steps of the flowchart of FIG. **6** performed by the base station client **11***a*, **12***a*, **13***a* of the embodiment of the system **1**, **5** of FIG. **8**. More specifically, step S**61** of FIG. **6** is illustrated in greater detail in steps S**901** to S**905** of FIG. **9**, and step S**62** of FIG. **6** is illustrated in greater detail in steps S**906** to S**913** of FIG. **9**. That is, steps S**901** to S**905** describe in greater detail the steps performed by the base station client **11***a* in the downlink, and steps S**906** to S**913** describe in greater detail the steps performed by the base station client **11***a*, **12***a*, **13***a* in the uplink.

In step S**901**, the base station client **11***a*, **12***a*, **13***a* receives the RLC PDUs over the Giga-Bit Ethernet interface **401**, **552** of the base station client **11***a*, **12***a*, **13***a* from a corresponding BBU **541**, **551**.

In step S**902**, the base station client **11***a*, **12***a*, **13***a* converts the RLC PDUs into information on logical channels. The conversion in step S**902** may include: performing a ciphering and integrity protection process on PDCP SDUs encapsulated in the RLC PDUs using the security entity **403** of the base station client **11***a*, **12***a*, **13***a*. Conventionally, ciphering and integrity protection of PDCP SDUs is performed by specialized hardware implemented by a conventional eNodeB to perform PDCP processing. In this embodiment, ciphering and integrity protection is performed by the security entity **403** of the base station client **11***a*, **12***a*, **13***a* which is separate to the PDCP processing entity **212** of the BBU **541**, **551**.

In step S**903**, the base station client **11***a*, **12***a*, **13***a* receives RB resource allocations and a CFI for a TTI from the MAC-PS processing entity **215** of the BBU **541** over the Giga-bit Ethernet Interface **401** from the BBU **541**, **551**. It is envisaged that the MAC-PS processing entity **215** may perform downlink MAC sub-layer packet scheduling operations and generate RB resource allocations and CFIs.

In step S**904**, the base station client **11***a*, **12***a*, **13***a* converts the information on the logical channels into information on transport channels according to the received RB resource allocations. This conversion is performed by the MAC (DL) processing entity **404** at the base station client **11***a*, **12***a*, **13***a*.

In step S**905**, the base station client **11***a* converts the information on the transport channels into RF signals suitable for transmission to the UEs. The conversion is performed by the PHY processing entity **409** of the base station client **11***a*. The RF signals are then transmitted to the UEs by the RF unit **410** and the antenna unit **411** of the base station client **11***a*, **12***a*, **13***a*.

Turning to steps S**906** to S**913** of FIG. **9**, as indicated above, these steps correspond to step S**62** of FIG. **6**. That is, steps S**906** to S**913** describe in greater detail the steps performed by the base station client **11***a* in the uplink.

In step S**906**, the base station client **11***a*, **12***a*, **13***a* receives the RF signals from the UEs.

In step S**907**, the base station client **11***a*, **12***a*, **13***a* converts the RF signals received from the UEs into information on transport channels. The conversion is executed by the PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*.

In step S**908**, the base station client **11***a*, **12***a*, **13***a* converts at least some of the information on the transport channels into packet signals. The information on the transport channels being converted may include received CQI reports, ACK/NACK, RACH preambles and MAC CE information from the UEs.

In step S**909**, the base station client **11***a*, **12***a*, **13***a* transmits the packet signals obtained in step S**908** to the MAC-PS processing entity **215** of the BBU **541** over the Giga-bit Ethernet Interface **401**.

In step S**910**, the MAC (UL) processing entity **406** of the base station client **11***a*, **12***a*, **13***a* converts the rest of the information (that is, the rest of the information not converted in step S**908**) on the transport channels into information on logical channels. It is envisaged that the MAC (UL) processing entity **406** may also be responsible for scheduling of UEs in the uplink.

In step S**911**, the base station client **11***a*, **12***a*, **13***a* converts the information on the logical channels into information on radio bearers using the RLC processing entity **407** and the PDCP processing entity **408**. The conversion includes: con-

verting the information on the logical channels into PDCP SDUs; performing de-ciphering and integrity protection on the PDCP SDUs; and converting the deciphered PDCP SDUs into the corresponding information on radio bearers.

In step **S912**, the base station client **11***a*, **12***a*, **13***a* determines the information on radio bearers and transmits the information on the radio bearers as packet signals over the Giga-bit Ethernet Interface **401** to the BBU **541**, **551**. The information on the radio bearers may include packets received in the uplink in the user plane, and packets received in the uplink in the control plane for RRC.

In step **S913**, the OAM entity **402** of the base station client **11***a*, **12***a*, **13***a* transmits/receives OAM/control and configuration information to/from the OAM **51** at the VCP **3**.

FIG. **10** is a flowchart illustrating in greater detail the steps of the flowchart of FIG. **7** performed by the base station server **10** of the system **1**, **5** of FIG. **8**. More specifically, step S**72** of FIG. **7** is illustrated in greater detail in steps S**1002** to S**1003** of FIG. **10**, and step S**73** of FIG. **6** is illustrated in greater detail in steps S**1004** to S**1005** of FIG. **10**. That is, steps S**1002** to S**1003** describe in greater detail the steps performed the BBU **541**, **551** in step S**72** of FIG. **7** in the downlink, and steps S**1004** to S**1005** describe in greater detail the steps performed by the base station client **11***a*, **12***a*, **13***a* in step S**73** of FIG. **7** in the uplink.

In step S**1001**, the BBU **541**, **551** receives scheduling control and coordination information of the UEs within a cluster of cells/base station clients **11***a*, **12***a*, **13***a* from the cell coordination scheduler **527**.

In step S**1002**, the PDCP processing entity **212** of the BBU **541**, **551** receives information on radio bearers from a connection point at a core network, and converts the information on radio bearers into information on logical channels.

In step S**1003**, the RLC processing entity **213** of the BBU **541**, **551** converts the information on the logical channels into one or more RLC PDUs. Then, the BBU **541** transmits the RLC PDUs over the Giga-bit Ethernet Interface **53** of the VCP **3** to the security entity **403** of the base station client **11***a*, **12***a*, **13***a*. As indicated above, ciphering and integrity protection on the information on the logical channels is performed by the security entity **403** of the base station client **11***a*, **12***a*, **13***a*.

Turning to steps S**1004** to S**1005** of FIG. **10**, these steps correspond to step S**73** of FIG. **7**. That is, steps S**1004** to S**1005** describe in greater detail the steps performed by the base station client **11***a*, **12***a*, **13***a* in the uplink.

In step S**1004**, the MAC-PS processing entity **215** of the BBU **541**, **551** generates RB resource allocations and a CFI for UEs within radio service coverage for a TTI of a pre-configured duration. It is envisaged that the MAC-PS processing entity **215** may generate RB resource allocations and a CFI based on scheduling control and coordination information of UEs generated by the cell coordination scheduler **527**.

In step S**1005**, the BBU **541**, **551** transmits the RB resource allocations and the CFI from the MAC-PS processing entity **215** over the Giga-bit Ethernet Interface **53** of the VCP **3** to the base station client **11***a*, **12***a*, **13***a*.

In step S**1006**, the BBU **541**, **551** receives from the base station client **11***a*, **12***a*, **13***a* packet signals containing information required for the MAC (DL) processing entity **404**. The information required may include some of the information on the transport channels being converted at the base station client **11***a*, **12***a*, **13***a*, and may include received CQI reports, ACK/NACK, RACH preambles and MAC CE information from one or more UEs.

In step S**1007**, the VCP **3** receives information on radio bearers as packet signals from the base station client **11***a*, **12***a*, **13***a* over the Giga-bit Ethernet Interface **53** of the VCP **3**. More specifically, the RRC processing entity **211** of the BBU **541** receives packet signals in the control plane for RRC packets in the uplink, and the connection point at the core network receives packet signals in the user plane in the uplink via the VCP **3**.

In step S**1008**, the OAM **51** of the VCP **3** transmits/receives OAM/control and configuration information to/from OAM entities **402** of the base station client **11***a*, **12***a*, **13***a*. The step S**1008** may be performed simultaneously along with the previously mentioned steps S**1001** to S**1007**.

FIG. **12** is a flowchart illustrating in greater detail the steps of the flowchart of FIG. **6** performed by the base station client **115** of the alternative embodiment of the system **111** of FIG. **11**. Most of the steps of FIG. **12** correspond to the steps of FIG. **9**. Specifically, steps S**1201** and S**1203** to S**1213** of FIG. **12** correspond to steps S**901** and S**903** to S**913** of FIG. **9**. The difference between FIG. **12** and FIG. **9** is that ciphering and integrity protection on PDCP SDUs encapsulated in RLC PDUs is performed by the security entity **403** of the base station client **11***a*, **12***a*, **13***a* in step S**902** of FIG. **9**, whereas ciphering and integrity protection on PDCP SDUs encapsulated in RLC PDUs is not performed by the base station client **115** in step S**1202** of FIG. **12**.

FIG. **13** is a flowchart illustrating in greater detail the steps of the flowchart of FIG. **7** performed by the alternative embodiment of the system **111** of FIG. **11**. Most of the steps of FIG. **13** correspond to the steps of FIG. **10**. Specifically, steps S**1301** and S**1303** to S**1308** of FIG. **13** correspond to steps S**1001** and S**1003** to S**1008** of FIG. **10**. The difference between FIG. **13** and FIG. **10** is that ciphering and integrity protection on PDCP SDUs encapsulated in RLC PDUs is performed by the PDCP processing entity **220** of the BBU **114** during conversion of the information on the radio bearers into the information on the logical channels in step S**1302** of FIG. **13**, whereas ciphering and integrity protection on PDCP SDUs encapsulated in RLC PDUs is not performed by the BBU **541**, **551** in step S**1002** of FIG. **10**.

Potential Advantages and/or Modifications in Report of the System

As indicated above, the functional components of the system **1**, **5**, **111** is split between the BBU **541**, **551**, **114** and the base station client **11***a*, **115** such that processing that are more latency critical is performed by the base station client **11***a*, **12***a*, **13***a*, **115** (that is, at a cell site where UEs are located), rather than the BBU **541**, **551**, **114**. Thus, when compared to a system where latency critical processing entities are centralized at a location remote from cell sites, the system **1**, **5**, **111** is advantageous in that it allows a reduction in data throughput requirements (that is, the required amount of data throughput) between the centralized base station server **10** and the remote base station clients **11***a*, **12***a*, **13***a*, **115**.

Also, by centralizing some of the baseband processing performed by a conventional eNodeB at a single base station server **10**, the system **1**, **5**, **111** advantageously allows efficient and dynamic usage of processing power which is otherwise distributed monolithically at multiple conventional eNodeBs. This may also lead to significant cost savings to eNodeB operators in terms of reduced CAPEX and OPEX due to a reduction in the number of cell sites.

Also, by performing PHY layer Digital Signal Processing (DSP) and RF processing at the base station clients **11***a*, **12***a*, **13***a*, **115**, the system **1**, **5**, **111** advantageously minimizes transmissions between the base station clients **11***a*, **12***a*, **13***a*, **115** and the base station server **10**.

When compared to a system where all baseband processing is performed at a cloud-based baseband processor, the system

1, 5, 111 is advantageous in that the data rate required between the base station server 10 and each base station client 11a, 12a, 13a, 115 may be lower because PHY layer processing is performed at the point of transmission (that is, by the RRH 45 of the base station client 11a, 12a, 13a, 115).

Assuming that some optical regeneration between the VCP 3 and base station client 11a, 12a, 13a, 115, the system 1, 5, 111 allows for a maximum cable distance of around 130 km (as PHY layer processing is performed at the point of transmission by the RRH 45). Thus, when compared to a system where all baseband processing is performed at a cloud-based baseband processor, the system 1, 5, 111 is advantageous in that it allows a significant separation range between the VCP 3 and each base station client 11a, 12a, 13a, 115.

Also, when compared to a centralized system where HARQ processing is centralized, the system 1, 5, 111 is advantageous in that HARQ processing can be efficiently performed at each base station client 11a, 12a, 13a, 115.

Also, it is envisaged that the system 1, 5, 111 meets the critical timing requirement of a sub-frame time budget of 1 millisecond, as typically required for systems conforming to the 3GPP LTE standard.

Also, it is envisaged that the system 1, 5, 111 meets the critical timing requirement of less than 5 ms for one way packet delay in an unloaded network, as typically required for systems conforming to the 3GPP LTE standard. For example, assuming that the delay for the optical fibre link between the base station server 10 and a base station client 11a, 12a, 13a, 115 takes the following into account eNodeB processing (from PDCP sub-layer to L1 layer) of 0.8 ms, transmission and reception, TTI, UE processing time of 0.8 ms, and a maximum propagation delay of 0.3 ms (assuming a 100 km cell distance), the one way delay $T_D=T_{eNodeB}+T_{TTI}+T_P+T_{UE}=2.9$ ms, where T_D denotes the one way delay, T_{eNodeB} denotes the eNodeB processing time, T_P denotes maximum propagation delay, and T_{UE} denotes the UE processing time. Assuming that HARQ retransmissions occur every 8 ms with a probability of 10% (for a non-loaded network), the maximum delay $T_{max}=2.9+0.8=3.7$ ms. This results in a one way delay time budget of 1.3 ms which is smaller than the required one way packet delay limitation of 5 ms. If we make the same assumptions, the maximum cable distance between the base station server 10 and a base station client 11a, 12a, 13a, 115 is 250 km which is typically sufficient for whole city coverage.

In the system 1, 5, 111, base station deployment density can be increased by increasing the number of base station clients 11a, 12a, 13a, 115 without deployment of additional base station servers 10. In addition, as the base station server 10 centralizes all of the baseband processing power, significant OPEX and CAPEX savings can be achieved and upgrades may be more easily achievable.

In the system 1, 5, 111, centralized pooling of processing resource can be exploited to provide significant benefits to operators of wireless/mobile communication networks. This may lead to cost savings, gather energy efficiency, capacity improvement and improved load balancing. For example, by housing baseband processing in one central location at the base station server 10, an operator of the system 1, 5, 111 can benefit from centralized management and operation of the radio network. The centralized management and operation of the wireless/mobile communication network may provide operation and management cost savings, and allow an operator of the system 1, 5, 111 to avoid the difficulty in finding a suitable site required for conventional eNodeBs and the continual operating expense of renting the real estate, ensuring an adequate power supply, shielding from the environment and securing the location. In addition, base station clients 11a, 12a, 13a, 115 are significantly less complex in terms of functionality, size and power requirements compared to conventional eNodeBs. Thus, expansion of the system 1, 5, 111 may be cheaper and faster.

Significant reduction in costs may be achieved because of the potential energy efficiency of the system 1, 5, 111. Centralizing baseband processing may reduce the cost of climate control and the other auxiliary site power costs conventionally required of conventional eNodeBs. In the system 1, 5, 111, small cells requiring low transmission power may be deployed. An important benefit of pooling all baseband processing in the system 1, 5, 111, is that there may be more efficient usage of resource based on load conditions. Processing resource can be allocated from areas which have lower capacity to those requiring higher capacity. For instance, the base station clients 11a, 12a, 13a, 115 can effectively be turned off overnight when there is no traffic activity within the coverage area of the base station clients 11a, 12a, 13a, 115. Additionally, the network may become more adapted to non-uniform traffic where processing load from a heavily loaded BBU 541, 551, 114 may be transferred to other under-utilized BBUs 541, 551, 114 of the base station server 10.

The centralized architecture of the system 1, 5, 111 can be exploited to improve system capacity. For example, channel status information/channel quality information may be reported by active UEs throughout cell coverage areas to the base station server 10 for utilization by cell coordination scheduler 527 to improve system capacity. For instance, when the cell coordination scheduler 527 allocates radio resource for one cell, the cell coordination scheduler 527 can take into account conditions in neighbouring cells as well as the currently serving cell. Also, the centralized architecture of the system 1, 5, 111 can be exploited to implement joint processing and scheduling to combat inter-cell interference (ICI).

Since baseband processing is centralized at the base station server 10, there is a potential for simplifying inter-eNodeB communication in the system 1, 5, 111. This allows consideration of multi-site reception and transmission techniques. Multi-site reception of a packet from a UE at multiple eNodeBs can enhance cell capacity. This may decrease the number of required retransmissions. Also, joint scheduling or beamforming techniques in the downlink may be used by the system 1, 5, 111, as BBUs 541, 551, 114 are centralized at the base station server 10.

Centralizing baseband processing at the base station server 10 allows global radio resource management (or joint radio resource management) to be implemented in the system 1, 5, 111. For instance, centralized BBUs 541, 551, 114 can more easily perform joint processing and scheduling to mitigate inter-cell interference (ICI) and thus improve spectral efficiency. It is envisaged that spectrum efficiency of UEs at cell edges can be improved using global radio resource management strategies such as Dynamic Carrier Scheduling (CS), Dynamic Packet Scheduling (PS), Inter-Cell Interference Coordination (ICIC) and Power Control. The global radio resource management may also be performed in multi-cells conditions within a number of cells consisting in a cluster in a static or semi-static way. Also, a subset of cells within a cluster can cooperate in transmission to any UE associated with the cluster (for instance, cooperative transmission to the UE), and thus implement Coordinated Multi-Point (CoMP) transmission/reception. Therefore, BBUs 541, 551, 114 at the VCP 3 can more easily resolve network dynamics, adopt flexible spectrum usage, and accommodate interference in the wireless/mobile communication network.

It will be understood to persons skilled in the art of the invention that many modifications may be made to the system **1**, **5**, **111** (in particular, to the base station server **10** and/or one or more of the base station clients **11***a*, **12***a*, **13***a*, **115**) without departing from the spirit and scope of the invention.

For example, additional improvements in uplink capacity may be achieved by performing cooperative scheduling/transmission techniques in the VCP **3**, the uplink of the eNodeB protocol stack can operate locally at the cell site and thus may be implemented completely in the base station client **11***a*, **12***a*, **13***a*, **115**. The following descriptions illustrate such implementation in more details.

In the system **1**, **5**, **111**, BBUs **541**, **551**, **114** can work together in a large physical baseband resource pool. Signalling, traffic data and channel state information (CSI) of active UEs can be easily shared by BBUs **541**, **551**, **114** within a cluster of the base station server **10**. The centralized architecture of the system **1**, **5**, **111** can be exploited to implement joint processing and scheduling to mitigate inter-cell interference (ICI) and improve spectral efficiency. For example, as opposed to conventional systems, inter-cell interference coordination (ICIC) can be implemented under the C-RAN infrastructure.

The system **1**, **5**, **111** may implement dynamic circuit switching to improve load balance and overall operational reliability (that is, failure protection). The overall carrier resource utilization can be increased by sharing baseband processing resources of multiple base station servers **10**. This sharing of resources may allow multiple users to dynamically access the air interface. Also, dynamic packet switching may be adopted to provide UEs with flexible spectrum usage, and resources may be dynamically allocated according to interference and traffic volume, to guarantee Quality of Service as well as to achieve high capacity.

In respect of the user plane, the connection point (such as a GTP-U Tunnel end point) at the core network may be implemented by the BBU **541**, **551**, **114** of VCP **3** for the downlink. Optionally, the connection point may be also implemented by the BBU **541**, **551**, **114** of the VCP **3** for the uplink. The system **1**, **5**, **111** can support Frequency Division Duplex (FDD) mode and Time Division Duplex (TDD) mode.

All base station clients **11***a*, **12***a*, **13***a*, **115** may be synchronized using Global Positioning System (GPS) clock timebase. The reference for system timing (for example, system frame number) may be at the base station clients **11***a*, **12***a*, **13***a*, **115**. For events that occur on Single Frequency Network (SFN) boundaries, such as handover commands or system information broadcasts, the VCP **3** may maintain such time offsets to each base station client **11***a*, **12***a*, **13***a*, **115**.

In the downlink, ROHC may be fully implemented by the BBUs **541**, **551**, **114** of the VCP **3**. ROHC may be exploited to compress IP packet headers when it is necessary. The system **1**, **5**, **111** may support the option of operating with no ciphering. Disabling of integrity protection may be optional. Security operations may be implemented by the security entity **403** of the base station client **11***a*, **12***a*, **13***a*, **115**. In the downlink, a PDCP SDU transmitted from the BBU **541**, **551**, **114** to the base station client **11***a*, **12***a*, **13***a*, **115** may remain un-ciphered until it reaches the base station client **11***a*, **12***a*, **13***a*, **115**. Accompanying a PDCP PDU and associated with that PDCP PDU may be metadata containing the information required to encrypt and integrity protect/integrity check the PDU at a later time. The Metadata may consist of PDCP PDU lengths and offsets within RLC PDU depending on the RLC headers sizes and Length Indicators. These offsets may be kept in the metadata as the data flows through the protocol stack of an eNodeB. Segmented PDU may be taken into account in transmission across "the Split". Additionally, regarding uplink transmission on the PDCP sub-layer operations of an eNodeB, the uplink PDCP may be fully implemented by the base station client **11***a*, **12***a*, **13***a*, **115**.

In respect of the RLC sub-layer in the downlink, RLC processing may be fully implemented in an eNodeB instance of the BBU **541**, **551**, **114** of the VCP **3**. In the uplink, RLC processing may be fully implemented by the base station client **11***a*, **12***a*, **13***a*, **115**.

In respect of the MAC sub-layer in the downlink, the MAC-PS processing entity **215** may be located at the BBU **541**, **551**, **114** of the VCP **3**. The MAC-PS processing entity **215** may be responsible for scheduling the radio resources specific for one base station client **11***a*, **12***a*, **13***a*, **115** (or cell) among a limited number of UE per TTI. The MAC-PS processing entity **215** may operate on a TTI basis while being controlled by the cell coordination scheduler **527** of the VCP **3** and operating on a longer time basis. The cell coordination scheduler **527** may be responsible for high-level scheduling across all UEs in a cell or in a sector such that Quality of Service (QoS) and/or other metrics may be maintained for each radio bearer. On the other hand, the cell coordination scheduler **527** operates on a longer time-base compared to the MAC-PS processing entity **215** of the base station client **11***a*, **12***a*, **13***a*, **115** and may cover the situation where the total number of active UE per cell is greater than the number of UE capable of being scheduled by the MAC. The rest of downlink MAC sub-layer operations may be performed by the base station client **11***a*, **12***a*, **13***a*, **115**.

The MAC (DL) processing entity **404** at the base station client **11***a*, **12***a*, **13***a*, **115** may additionally perform the following operations: Downlink Shared Channel (DL-SCH) data transfer (including HARQ and multiplexing in the downlink), Paging Channel (PCH) transmission, Broadcast Channel (BCH) transmission, Discontinuous Reception, and MAC Reconfiguration and MAC Reset. The MAC sub-layer may receive RLC PDU per bearer, per UE or per TTI from the RLC sub-layer. Relevant control information may be derived from the MAC (DL) processing entity **404**. In order for latency to be less than 5 ms (as required by the 3GPP LTE standard), propagation time between the base station server and the base station client **11***a*, **12***a*, **13***a*, **115** may nominally be less than 1.3 ms. The propagation time may be more dependent in local IP routing environment which is dependent on the IP service provider network and Service Level Agreements (SLAs).

In respect of the MAC sub-layer, RB allocations per UE per TTI may be transmitted to the MAC (DL) processing entity **404** of the base station client **11***a*, **12***a*, **13***a*, **115**. Also, CQI reports received from a UE on a Physical Uplink Shared Channel (PUSCH) or a Physical Uplink Common Control Channel (PUCCH) may be sent from the MAC (UL) processing entity **406** and the PHY layer processing entity **409** at the base station client **11***a*, **12***a*, **13***a*, **115** to the MAC-PS processing entity **215** of the VCP **3**.

In respect of the MAC sub-layer, the MAC-PS processing entity **215** at the VCP **3** may use information from all scheduled UEs in the cell to optimize packet/radio resource scheduling for UEs taking channel conditions per UE into account. Downlink HARQ indications received from the UE may be sent from the MAC (UL) processing entity **406** and the PHY layer processing entity **409** at the base station client **11***a*, **12***a*, **13***a*, **115** to the MAC-PS processing entity **215** of the VCP **3**. The MAC-PS processing entity **21** may use such information for any retransmissions. For example, the MAC-PS processing entity **215** may not schedule a HARQ process from a UE in a TTI unless it knows the ACK/NACK status of the previous transmission for that HARQ process for that UE.

In respect of the MAC sub-layer, Random Access preambles received from UE in the RACH procedure may be sent to the MAC-PS processing entity **215** of the VCP **3**. The MAC-PS processing entity **215** of the VCP **3** may use this information to perform scheduling in respect of Random Access Response MAC messages. The interface between the MAC (UL) processing entity **406** of the base station client **11***a*, **12***a*, **13***a*, **115** and the MAC-PS processing entity **215** of the VCP **3** may support sending information about the MAC Control Elements (CE) in the MAC buffer to the MAC-PS processing entity **215**. The MAC-PS processing entity **215** may use this information to perform scheduling in respect of MAC CE messages. The MAC-PS processing entity **215** may generate a CFI every TTI for transmission on the Physical CFI Channel (PCFICH).

DCI Formats 0, 1x, 2x, 3x may be supported by the system **1**, **5**, **111**. Timing may be preserved over the base station server and the base station client **11***a*, **12***a*, **13***a*, **115** such that, for a UE or UE group identified by an Radio Network Temporary Identifier (RNTI), the DCI transmitted on the PDCCH in one TTI corresponds to the MAC Scheduling derived in the VCP **3** for the Downlink-Shared Channel (DL-SCH) TB transmitted on the Physical Downlink Shared Channel (PDSCH) in the same TTL

In respect of the DL-SCH, the Common Control Channel (CCCH), Dedicated Control Channel (DCCH) and Dedicated Traffic Channel (DTCH) may be supported. The MAC (DL) processing entity **404** of the base station client **11***a*, **12***a*, **13***a*, **115** may be responsible for mapping the Broadcast Control Channel (BCCH), CCCH, DCCH and DTCH onto the downlink shared channel (DL-SCH).

In respect of the BCH, BCCH may be supported. The MAC (DL) processing entity **404** of the base station client **11***a*, **12***a*, **13***a*, **115** may be responsible for mapping the BCCH onto BCH for transmission on the Physical Broadcast Channel (PBCH).

In respect of the PCH, Paging Control Channel (PCCH) may be supported. The MAC (DL) processing entity **404** of the base station client **11***a*, **12***a*, **13***a*, **115** may be responsible for mapping the PCCH onto PCH for transmission on the PDSCH. PCH TBs are associated with DCI which in turn are associated with a Paging Radio Network Temporary Identity (P-RNTI).

In respect of the Multicast Channel (MCH), Multicast Traffic Channel (MTCH) and Multicast Control Channel (MCCH) may be supported. The MAC (DL) processing entity **404** of the base station client **11***a*, **12***a*, **13***a*, **115** may be responsible for mapping the MTCH and MCCH onto the Multicast Channel (MCH).

In respect of the uplink, the MAC-PS processing entity **215** may be implemented by the base station client **11***a*, **12***a*, **13***a*, **115**. The MAC (UL) processing entity **406** of the base station client **11***a*, **12***a*, **13***a*, **115** may support the Uplink Shared Channel (UL-SCH). The MAC (DL) processing entity **404** and/or the MAC (UL) processing entity **406** of the base station client **11***a*, **12***a*, **13***a*, **115** may support RACH.

In respect of the PHY layer, the PHY layer processing entity **409** may be implemented by the base station client **11***a*, **12***a*, **13***a*, **115**. The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may support transmission of PBCH in the downlink. The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may support transmission of PDSCH in the downlink. The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may support reception of Physical Random Access Channel (PRACH), PUCCH and PUSCH in the uplink. The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may support transmission of Physical Multicast Channel (PMCH) in the downlink. The CFI provided by the MAC-PS processing entity **215** of the BBU **541** may be processed by the PHY layer processing entity **409** of the base station client **11***a* onto one PCFICH for transmission in the cell. The DCI (per UE or per group of UEs provided by the MAC-PS processing entity **215** may be processed by the PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** onto one PDCCH for each UE or UE group. The Physical Hybrid-ARQ Indicator Channel (PHICH) may transmit ACK/NACK based on the received UL-SCH Block Error indication per UE. The ACK/NACK may be transmitted at the correct timing according to synchronous HARQ operation in the UL.

The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may be implemented on commercially available devices such as off-the-shelf Small Cell System on a Chip (SoC) devices. These commercially available devices may contain on-chip hardware co-processors to implement Fast Fourier Transform (FFT) or turbo-coding algorithms as well as encryption and integrity protection algorithms. The PHY layer processing entity **409** of the base station client **11***a*, **12***a*, **13***a*, **115** may cipher all Data Radio Bearer (DRBs) which may include data in the user plane and Signaling Radio Bearers (SRBs) **1** and **2** which may include control/signalling information in the control plane. The PHY layer processing entity **409** the base station client **11***a*, **12***a*, **13***a*, **115** may also perform integrity protection for control/signalling information in the control plane.

For dynamic operation, the MAC-PS processing entity **215** of the BBU **541**, **551**, **114** may calculate the optimum CFI per TTI such that the lowest number of symbols used is sufficient to control the instantaneous data transmission requirement for that TTI. For static operation, the MAC-PS processing entity **215** of the BBU **541**, **551**, **114** may set a CFI based on the number of UE contexts in the cell such that for low UE numbers, CFI=1; for medium UE numbers CFI=2; and for high UE numbers, CFI=3.

In the downlink, the DCI may consist of downlink scheduling assignments, HARQ information and power control information per UE or UE group as well as an RNTI identifying the UE or UE group. The downlink scheduling assignments may be an allocation of Radio Bearer resource which comes from the MAC (UL) processing entity **406** of the base station client. This allocation may consist of Allocation Type, RB Allocation, and Modulation Coding Scheme (MCS). The HARQ information may include: HARQ Process Number, NDI, and RV. This HARQ information may be input to the HARQ entity implemented by the base station client **11***a*, **12***a*, **13***a*, **115**. For DCIO, input is required from the MAC (UL) processing entity **406** at the base station client **11***a*, **12***a*, **13***a*, **115** of the eNodeB corresponding to a Scheduling Grant given in response to a previous Scheduling Request from the UE in the uplink. The Scheduling Grant may include the RB Allocation, MCS and RV information, and may also include power control information. Additionally, the Grant may also include a CQI Request allowing aperiodic channel status request.

Further aspects of the system **1**, **5**, **111** will be apparent from the above description of the system **1**, **5**, **111**. Persons skilled in the art will also appreciate that any of the methods described above could be embodied in program code. The program code could be supplied in a number of ways, for example on a tangible computer readable medium, such as a disc or a memory (for example, that could replace part of the memory unit **32** of the VCP **3** or the memory unit **42** of a base

station client **11***a*) or as a data signal (for example, by transmitting it from the base station server **10**).

It is to be understood that, if any prior art is referred to herein, such reference does not constitute an admission that the prior art forms a part of the common general knowledge in the art in any country.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, that is to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

The invention claimed is:

1. A system for converting between higher-layer packets and lower-layer packets, comprising:

a downlink base station server performs a conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet; and

an uplink base station client performs a conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet,

wherein the downlink base station server performs the conversion of the at least one downlink higher-layer packet to the at least one downlink lower-layer packet by:

receiving the at least one downlink higher-layer packet;

converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet; and

transmitting the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device, and

wherein the uplink base station client performs the conversion of the at least one uplink lower-layer packet to the at least one uplink higher-layer packet by:

receiving the at least one uplink lower-layer packet over an uplink channel from an uplink user device;

converting the at least one uplink lower-layer packet to the at least one uplink higher-layer packet; and

transmitting the at least one uplink higher-layer packet to an uplink base station server.

2. The system as claimed in claim **1**, wherein the downlink base station server is located at a first site, and the uplink base station client is located at a second site remote from the first site.

3. The system as claimed in claim **1**, further comprising the uplink base station server, wherein the downlink base station server and the uplink base station server are implemented in the same device.

4. The system as claimed in claim **1**, further comprising the downlink base station client, wherein the downlink base station client and the uplink base station client are implemented in the same device.

5. The system as claimed in claim **1**, wherein the downlink channel is a downlink radio channel, and the uplink channel is an uplink radio channel.

6. The system as claimed in claim **1**, wherein the downlink base station server is connected to a plurality of downlink base station clients.

7. The system as claimed in claim **6**, wherein the downlink base station server is connected to each downlink base station client via a respective one of a plurality of downlink optical fibre links.

8. The system as claimed in claim **6**, wherein the downlink base station server is connected to each downlink base station client via a respective one of a plurality of downlink Ethernet connections.

9. The system as claimed in claim **1**, wherein the uplink base station client is connected to the uplink base station server via an uplink optical fibre link.

10. The system as claimed in claim **1**, wherein the uplink base station client is connected to the uplink base station server via an uplink Ethernet connection.

11. The system as claimed in claim **1**, wherein:

each downlink higher-layer packet is a Service Data Unit (SDU) that conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard,

each uplink higher-layer packet is a SDU that conforms to the 3GPP LTE standard,

each downlink lower-layer packet is a Packet Data Unit (PDU) that conforms to the 3GPP LTE standard, and

each uplink lower-layer packet is a PDU that conforms to the 3GPP LTE standard.

12. The system as claimed in claim **1**, wherein each downlink higher-layer packet corresponds to an Internet Protocol (IP) packet, and each uplink higher-layer packet corresponds to an IP packet.

13. A method of converting between higher-layer packets and lower-layer packets, comprising:

performing a conversion of at least one downlink higher-layer packet to at least one downlink lower-layer packet at a downlink base station server; and

performing a conversion of at least one uplink lower-layer packet to at least one uplink higher-layer packet at an uplink base station client,

wherein performing the conversion of the at least one downlink higher-layer packet to the at least one downlink lower-layer packet at the downlink base station server comprises:

receiving the at least one downlink higher-layer packet;

converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet; and

transmitting the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device, and

wherein performing the conversion of the at least one uplink lower-layer packet to the at least one uplink higher-layer packet at the uplink base station client comprises:

receiving the at least one uplink lower-layer over an uplink channel from an uplink user device;

converting the at least one uplink lower-layer to the at least one uplink higher-layer packet; and

transmitting the at least one uplink higher-layer packet to an uplink base station server.

14. The method as claimed in claim **13**, wherein converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises segmenting the at least one downlink higher-layer packet into a plurality of downlink lower-layer packets according to a Radio Link Control (RLC) protocol.

15. The method as claimed in claim **13**, wherein converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises concatenating a plurality of downlink higher-layer packets into the at least one downlink lower-layer packet according to a Radio Link Control (RLC) protocol.

16. The method as claimed in claim 13, wherein converting the at least one downlink higher-layer packet to the at least one downlink lower-layer packet comprises reassembling the at least one downlink higher-layer packet as the at least one downlink lower-layer packet according to a Radio Link Control (RLC) protocol.

17. The method as claimed in claim 13, wherein the Radio Link Control (RLC) protocol conforms to the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard.

18. A base station server comprising:

at least one downlink packet transmitter, each downlink packet transmitter that:

receives at least one downlink higher-layer packet;

converts the at least one downlink higher-layer packet to at least one downlink lower-layer packet; and

transmits the at least one downlink lower-layer packet to a downlink base station client for transmission over a downlink channel to a downlink user device; and

at least one uplink packet receiver, each uplink packet receiver that:

receives from an uplink base station client at least one uplink higher-layer packet converted by the uplink base station client from at least one uplink lower-layer packet received by the uplink base station client over an uplink channel from an uplink user device; and

processes the at least one uplink higher-layer packet.

19. The base station server as claimed in claim 18, wherein the base station server comprises a plurality of uplink packet receivers, each uplink packet receiver being associated with a respective one of the plurality of uplink base station clients.

20. The base station server as claimed in claim 18, wherein the base station server comprises a plurality of downlink packet transmitters, each downlink packet transmitter being associated with a respective one of the plurality of downlink base station clients.

21. The base station server as claimed in claim 18, wherein the uplink packet receiver processes the at least one uplink higher-layer packet, by transmitting the at least one higher-layer packet to another one of the at least one downlink packet transmitter.

22. The base station server as claimed in claim 18, wherein the uplink packet receiver processes the at least one uplink higher-layer packet, by transmitting the at least one higher-layer packet to another base station server.

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